Effective Microbial Control Strategies for Main Breaks and Depressurization

Project 4307

Sponsored by the Water Research Foundation and the U.K. Drinking Water Inspectorate

HDR

AMERICAN WATER

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Project Purpose

Improve utility responses to main breaks and depressurization events to better protect public health.

Project Objectives

1. Evaluate the effectiveness of disinfection and operational practices to mitigate risks.

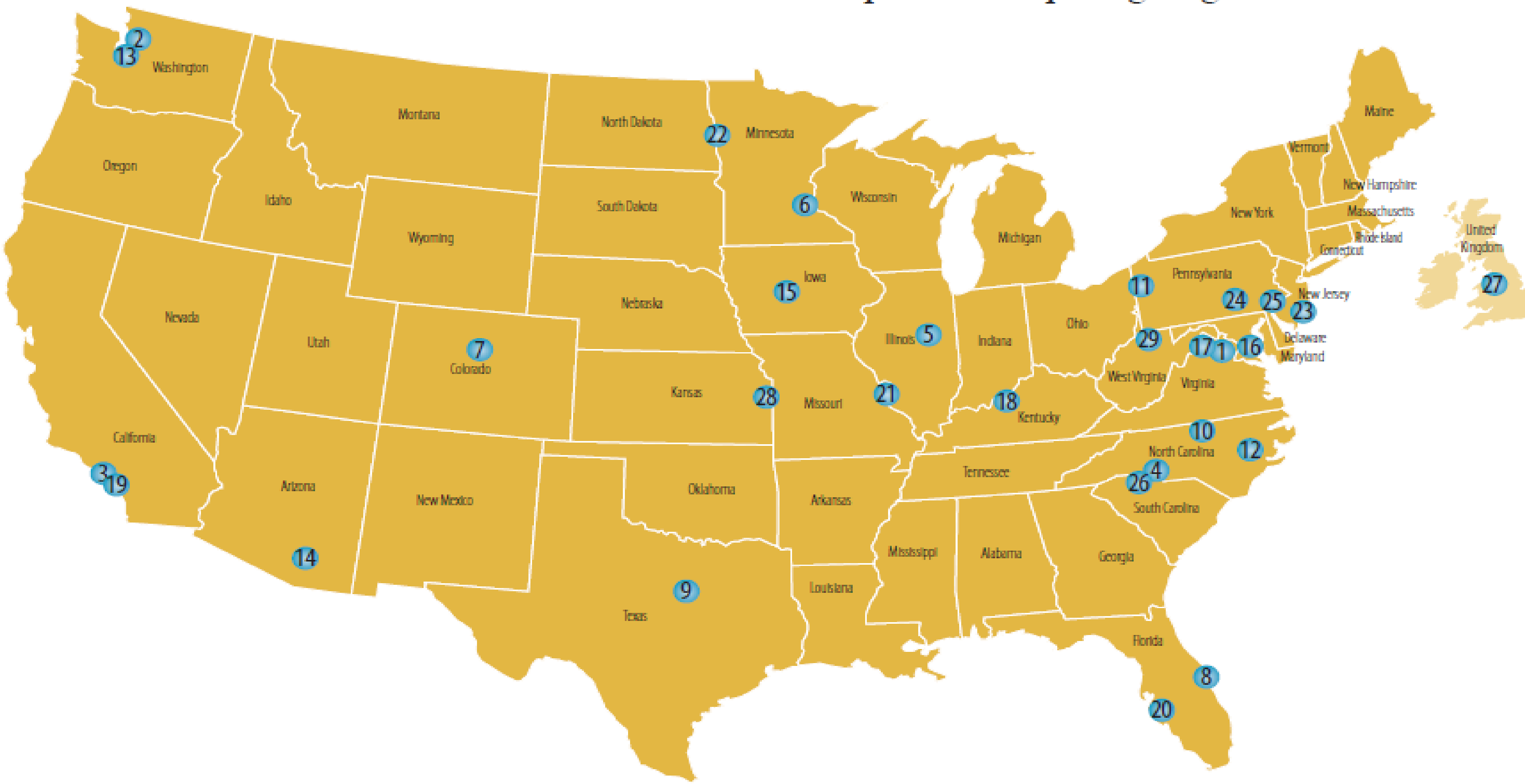
2. Identify parameters to quantify the level of control achieved.

Project Overview

- 2010 Solicited Research Program
- Project Schedule:
  - Project Start: October 15, 2010
  - Project End: June 15, 2013
- Project Budget:
  - Cash: $350,000
    (= $30,000 (UK DWI) + $320,000 (WaterRF)
  - Third Party Contribution: $331,000
  - Total: $827,559.80
- WaterRF Project Manager: Grace Jang

Participating Utilities

Map of Participating Organizations



Utilities Participating in Project Survey

- California American Water – Coronado
- California American Water – Larkfield District
- California American Water – Los Angeles
- California American Water – Monterey Division
- California American Water – Sacramento
- California American Water – Thousand Oaks/Newbury Park
- Charlotte Mecklenburg Utilities, NC
- City of Bellevue Utilities, WA
- City of Bloomington, IL
- City of Boulder, CO
- City of Cocoa, FL
- City of Fort Worth, TX
- City of Greensboro, NC
- City of Raleigh, NC
- City of Tucson Water Department, AZ
- District of Columbia Water and Sewer Authority, DC
- Los Angeles Department of Water & Power, CA
- Loudoun Water, VA
- Manatee County Utilities, FL
- Missouri American Water, MO
- Moorhead Public Service, MN
- New Jersey American Water, NJ
- Philadelphia Water Department, PA
- Seattle Public Utilities, WA
- Spartanburg Water, SC
- United Utilities, UK
- WaterOne, KS
- West Virginia American Water, WV

AWWA C651 Disinfecting Water Mains

- Three disinfection methods for both new construction and repairs:
  - Tablet method
    - Typical for new construction
    - Places calcium hypochlorite tablets at intervals along the pipe crown
    - Dose 25 mg/L with a detectable chlorine residual at the end of 24 hours
  - Continuous feed method
    - The water main filled water at a dosage of at least 25 mg/L 24 hours
    - Should have a residual of at least 10 mg/L
  - Slug method
    - Flow water through the pipeline with at least 50 mg/L for three hours

- Preliminary flushing (>2.5 ft/sec) for the continuous feed and slug methods
  - To eliminate air pockets and remove particulates
  - For 24-in or larger mains, a flushing alternative is to broom-sweep the main

- Verification of disinfection requires two clean coliform samples taken 24 hr apart (Turbidity, pH, and HPC samples may also be collected)

Project Approach

STEP 1	Define Terminology and Establish the Baseline of Practice
STEP 2	Conduct Laboratory and Pilot Studies and Risk Modeling
STEP 3	Identify/Pilot Test Field and Monitoring Activities
STEP 4	Develop Tiered Risk Management Strategy Including Multiple Barriers
STEP 5	Prepare Work Products and Final Report

STEP 1 HIGHLIGHTS:

QUESTIONNAIRE RESULTS

Step 1 Questionnaire

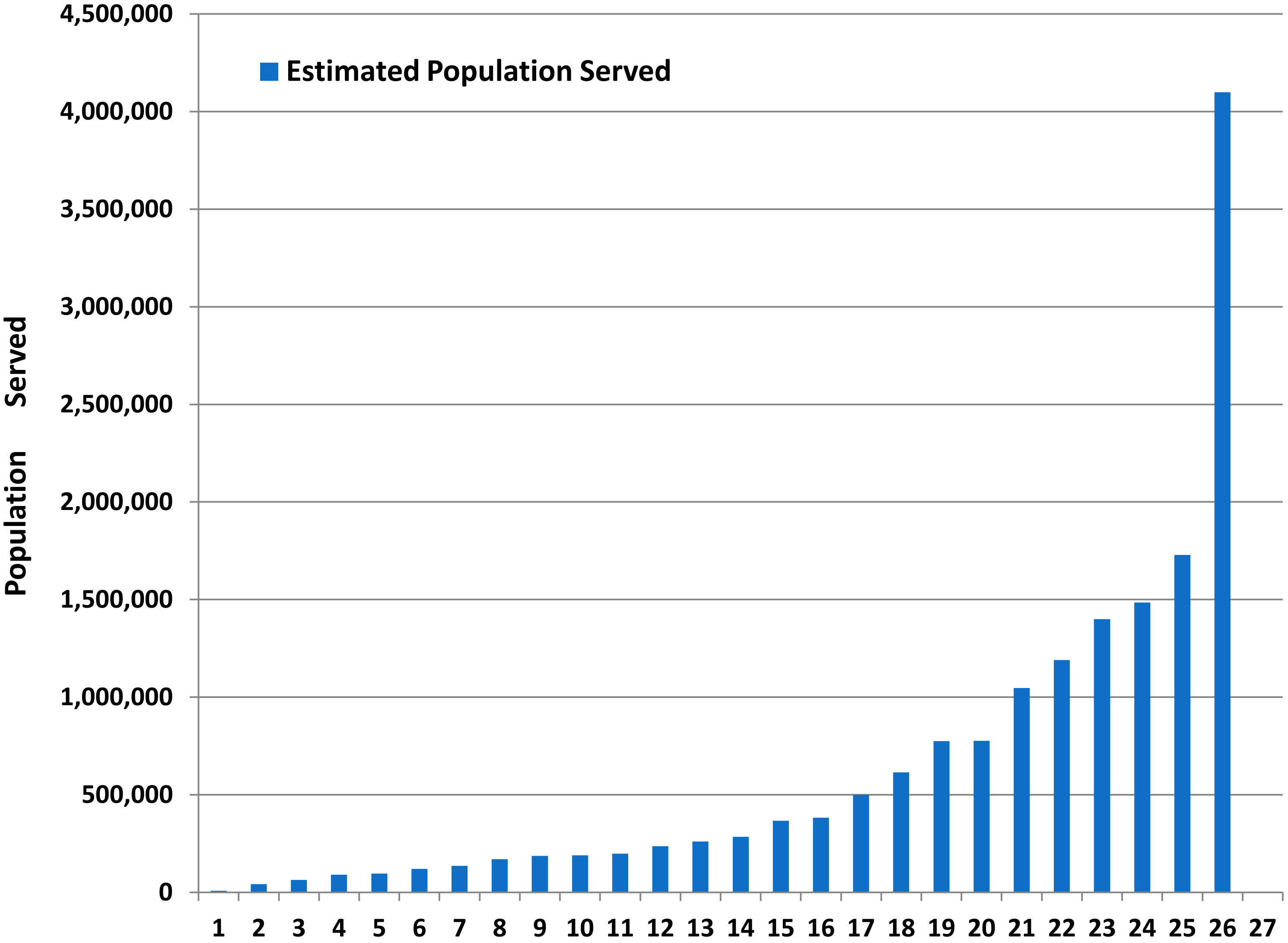
- Intended to gather data and procedures
- Questionnaire distributed with follow-up calls when needed
- Representative sample of industry
- Basis for selecting “Featured Programs”

What is the rate of main breaks (i.e. # / mile) that are encountered by your utility annually?

What criteria do you use for release-to-service after repairing a water main break?

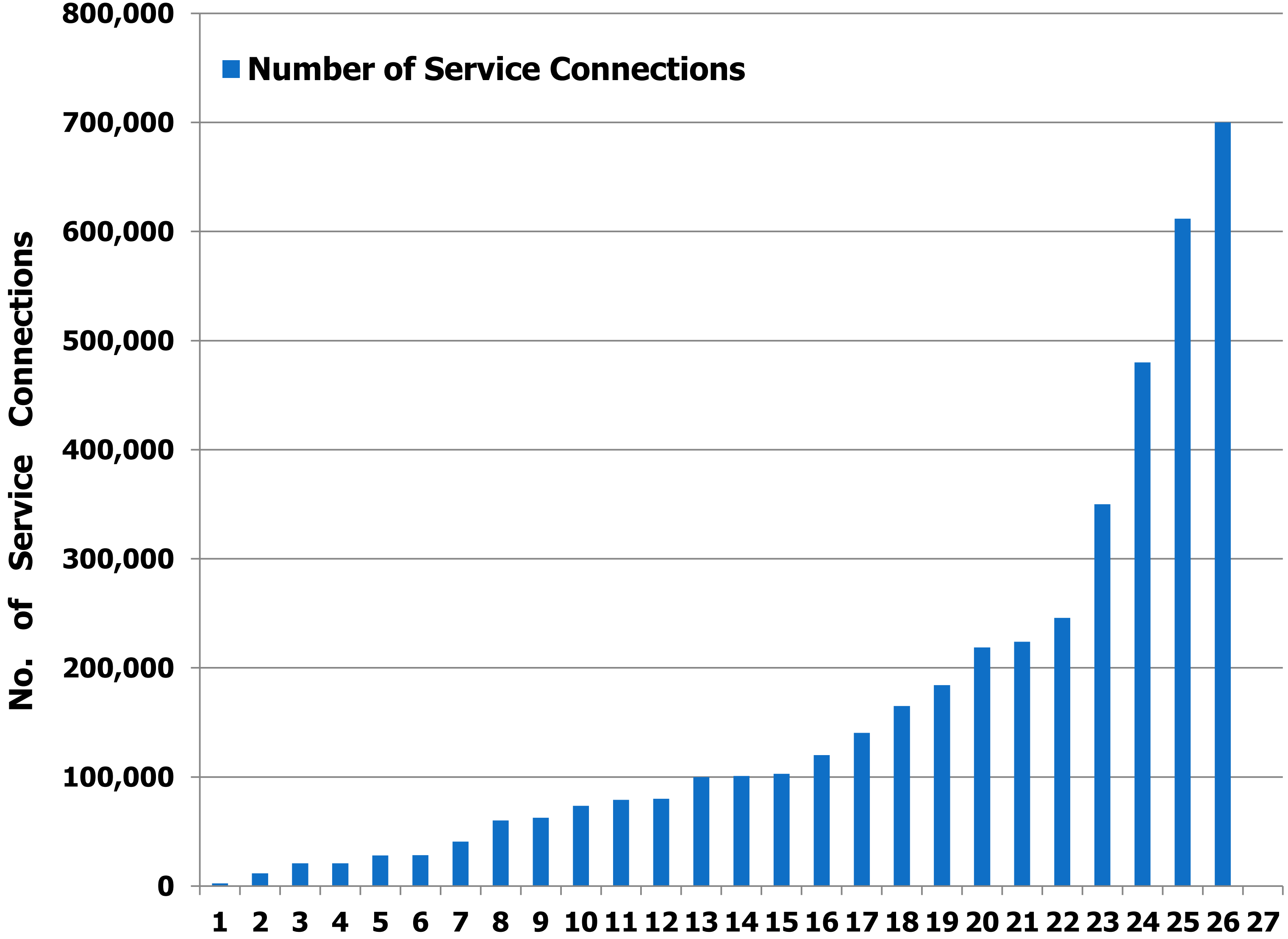
What is the typical crew size for repairing water main breaks for pipes larger/ smaller than 16-inches diameter?

Estimated Population Served: North American Participants



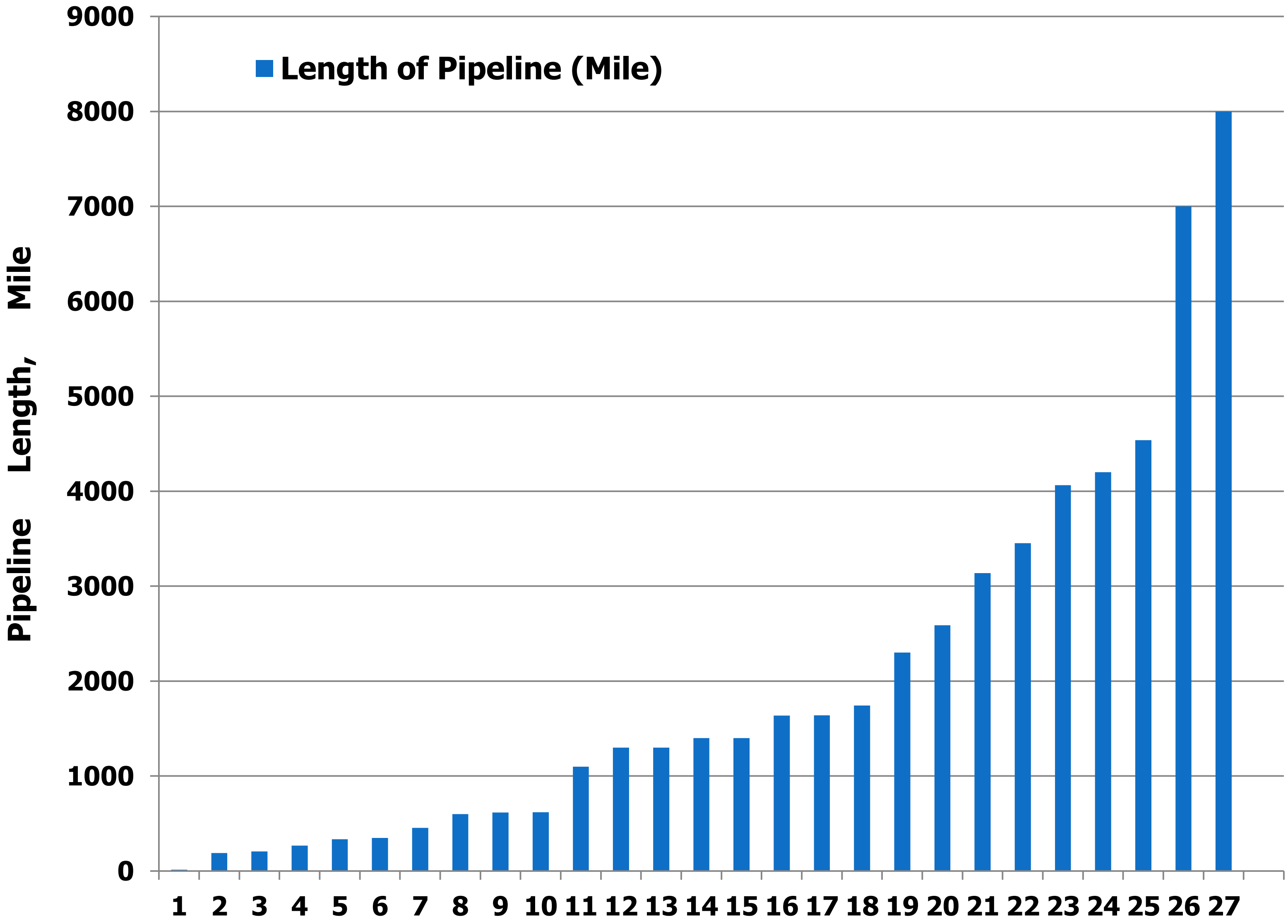
- Min Population – 7,800
- Max Population – 4,100,000

Service Connections: North American Participants



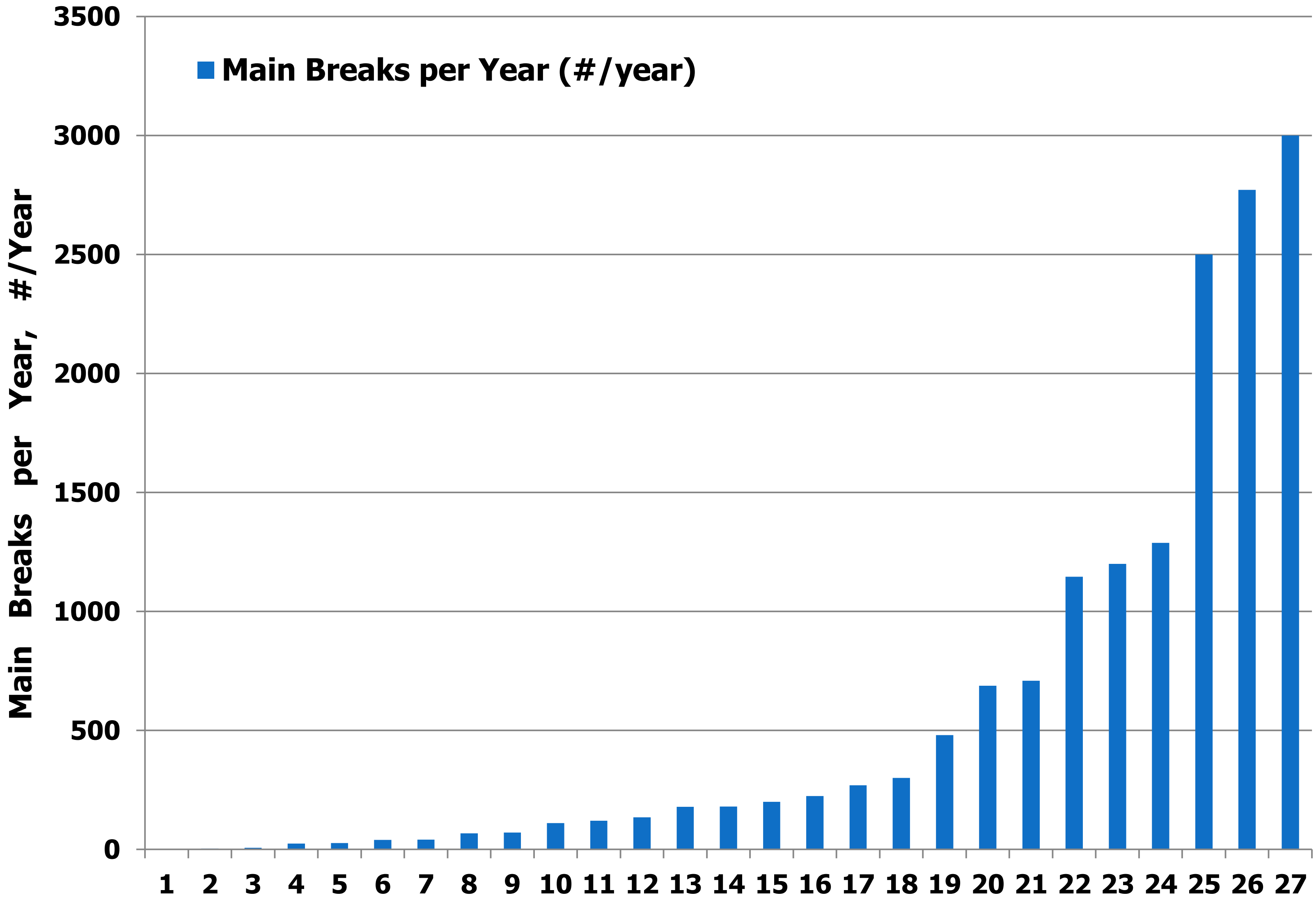
- Min Service Connections – 2,400
- Max Service Connections – 700,000
- Avg Service Connections – 163,544

Length of Pipeline: North American Participants



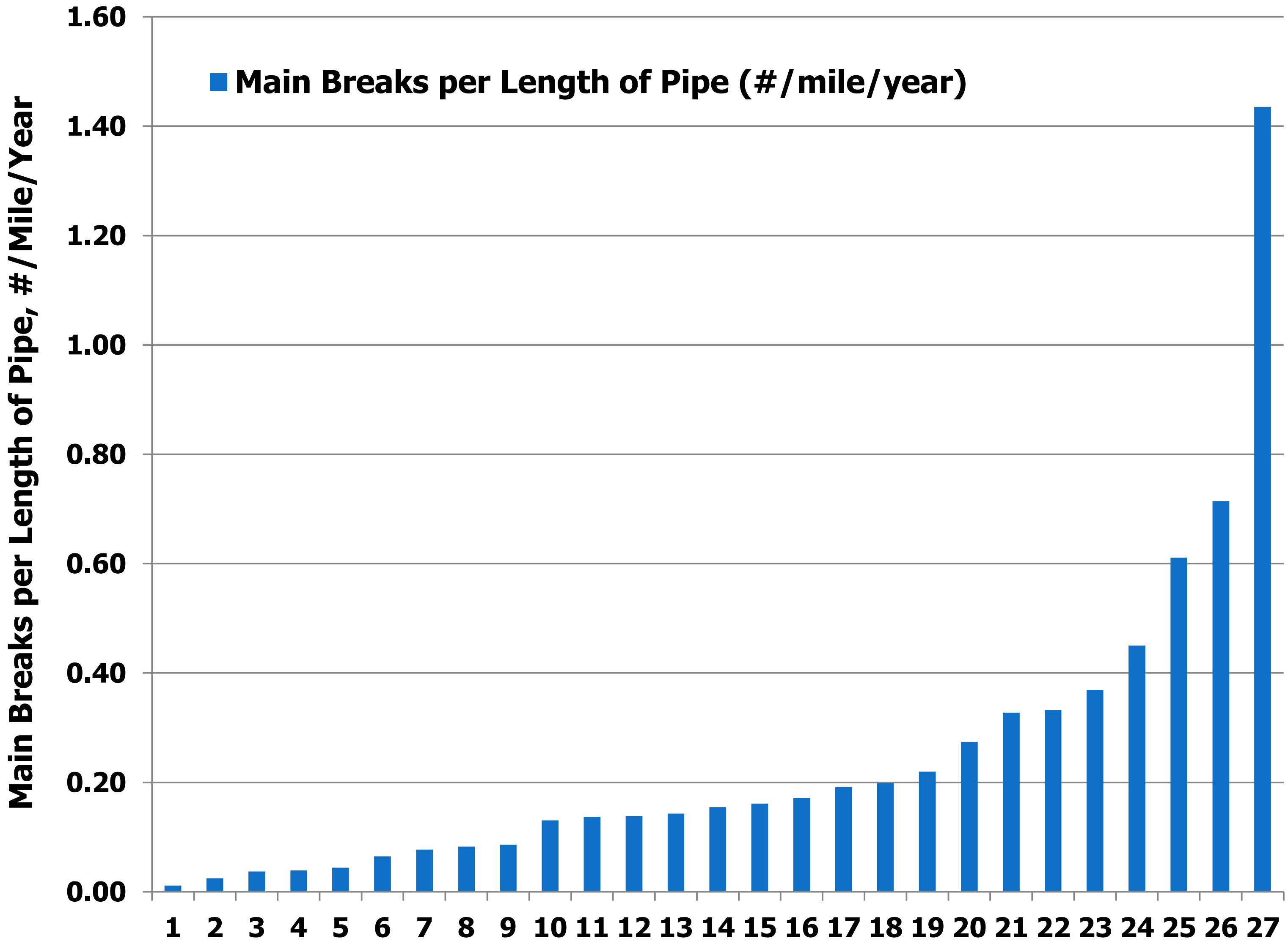
- Min Length – 13 Mile
- Max Length – 8,000 Mile
- Avg Length – 2,017 Mile

Main Breaks per Year: North American Participants



- Avg Breaks/Yr – 584
- Range – 1~3,000/Yr

Main Breaks per Length of Pipe: North American Participants



- Survey Avg – 0.25/Mile/Yr
- Range – 0.01~1.44/Mile /Yr
- National Avg – 0.27/Mile/Yr

Is There a Seasonal Component to the Break Frequency?

- Seasonal Impact: 70% Utilities (19 Utilities)
- No Impact: 30% Utilities (8 Utilities)

Season	Min.	Max.	Average
Winter	18%	79%	38.2%
Spring	4%	25%	14.5%
Summer	5%	39%	22.5%
Fall	7%	38%	24.9%

- Cold Weather is a Significant Factor

Does Your Utility Have Written Procedures for the Repair of Water Main Breaks?

- 67% Utilities (18 Utilities) Have Written Procedures.
- 33% Utilities (9 Utilities) Have No Written Procedures.
- Wide Variety of Procedures Noted.

Does Your Utility Provide Formal or Informal Training with Regard to Sanitary Practices During a Water Main Break Repair?

- 26 Utilities Out of 27 (96%) Provide Training.
- 17 Utilities Out of 26 (65%) Provide Refreshers.

Training Type	Utilities
Formal	6
Informal	16
Formal + Informal	4
No Training	1

- Most Utilities Provide Informal Training.

What Type of Disinfectant Residual is Used in Your System?

Disinfectant Type	Utilities
Chlorine	10
Chloramines	13
Both	4

Do You Use Any of the Methods Described in AWWA Standard C651 “Disinfecting Water Mains” as Part of the Repair Procedures for Smaller Main Breaks?

- 89% Utilities (24 Utilities) Follow Portions of AWWA Standard C651.
- 11% Utilities (3 Utilities) Do Not Follow AWWA Standard C651.

AWWA Method	Utilities
Trench Treatment	9
Swabbing of Pipe	19
Flushing	24
Disinfection Operation	17
Bacteriological Tests	17

Do You Use Any Criteria for Release-to-Service After Repairing a Water Main Break?

Criteria	Utilities
Flushing	27
Turbidity	11
Chlorine Residual	16

Does Your Utility Require Water Quality Sampling for Release-to-Service?

- 48% Utilities (13 Utilities) Require Water Quality Sampling.
- 52% Utilities (14 Utilities) Do Not Require Water Quality Sampling.

Does Your System Use Pressure Management Techniques?

Pressure Management Techniques	Utilities
Continuous Pressure Monitoring System(s)	22
Reduced Pressure During Off-peak Season	4
Other Techniques	4

Do You Maintain a Minimal Pressure During the Repair of Small Breaks, or is the Break Location Completely Isolated With No Flow?

Techniques	Utilities
Maintain Minimal Pressure	12
Isolation with No Flow	6
Both	9

Do You Monitor Pressure Away from the Break Location?

- 41% Utilities (11 Utilities) Monitor Pressure Away from the Break Location.
- 59% Utilities (16 Utilities) Do Not Monitor Pressure Away from the Break Location.

Have You Issued Boil Water Advisories of Any Size in the Past, and if so, How Often?

Boil Water Advisory Frequency	Utilities
1 or More per Year	5
Every 1 to 5 Years	3
Very Rare	11
Never	7

- Question Not Responded by One (1) Utility.

What is the Typical Crew Size for Repairing Water Main Breaks for Pipes 12-inches (30.5 cm) in Diameter and Smaller?

Typical Crew Size	Utilities
1	0
2	1
3	6
4	12
5	5
6	3
>6	0

- Most Utilities Have Crew Size of 4.

What is the Typical Crew Size for Repairing Water Main Breaks for Pipes Larger than 12-inches (30.5 cm) in Diameter?

Typical Crew Size	Utilities
1	0
2	0
3	2
4	11
5	8
6	3
>6	2

- Question Not Responded by One (1) Utility.
- Most Utilities Have Crew Size of 4.

Do You Dechlorinate the Flushed Water After Main Repairs?

- 62% Utilities (16 Utilities) Dechlorinate the Flushed Water.
- 38% Utilities (10 Utilities) Do Not Dechlorinate the Flushed Water.
- Question Not Responded by One (1) Utility.

What Types of Customer Contacts are Made Regarding Water Quality During a Main Break?

Types of Customer Contacts	Utilities
Instructions to Flush Premise Plumbing on Return to Service	8
Notification Only	11
Instructions to Flush Premise Plumbing and/or Notification	4
None	4

Summary of Program Elements found by Survey

What Was Found?

- Wide range of practices
- Majority have training; much is informal
- Majority follow parts of AWWA Standard C651 or U.K. Technical Guidance Notes

AWWA Method	Utilities
Trench Treatment	9
Swabbing of Pipe	19
Flushing	24
Disinfection Operation	17
Bacteriological Tests	17

Featured Programs

Fort Worth, TX

- Emergency response
- Leak detection procedures
- Excavation pit procedures
- Responses tied to type of break
- Flow chart for Boil Water Advisory (BWA) actions

Los Angeles (LADWP), CA

- Pollution prevention
- Disinfection and dechlorination
- Training materials with quizzes
- Flushing protocols

Featured Programs (Cont.)

New Jersey American Water

- Comprehensive Boil Water Advisory (BWA) guideline

Boulder, CO

- Main break notification and communication protocols

Charlotte-Mecklenburg, NC

- Training materials and performance evaluations

Denver, CO

- Flowchart for risk assessment

Project Tasks

Step 1: Define Terminology and Establish the Baseline of Practice

Step 2: Conduct Laboratory, Pilot Studies and Risk Modeling

Step 3: Identify/Pilot Test Field and Monitoring Activities

Step 4: Develop Tiered Risk Management Strategy Including Multiple Barriers

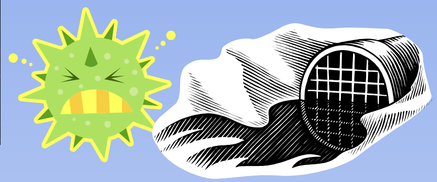
Step 5: Prepare Work Products and Final Report

Step 2 – What We Need to Know to Model Risk

- The disinfectant demand of the contaminating material
- The inactivation kinetics of microbial contaminants
- The effectiveness of removal of contamination by flushing
- The risk of the material remaining after disinfection and/or flushing

Step 2 Lab Studies & Microbial Risk Modeling

1. Pathogen levels in sewage (Meta-analysis of occurrence levels from literature)



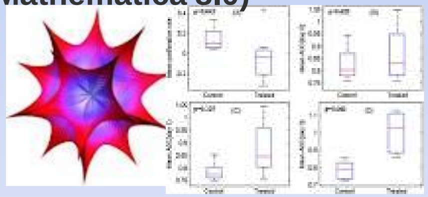
2. Main breaks and depressurization (Sewage intrusion and dilution)

3. Main break repairs and back to service: a) Flushing; b) Disinfection

4. Individual water intake

5. Dose-response models (Collected from literature)

6. Risk characterization (Monto-Carlo simulations in Mathematica 8.0)



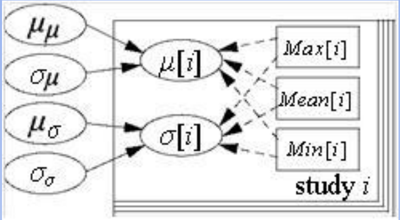
7. Risk management options

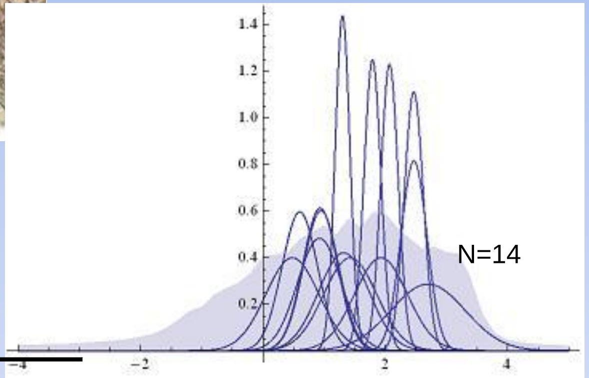
a) Compare with an acceptable annual risk of 10^{-4}

b) Flushing, disinfection, boil water advisory, etc.

Risk Model (1) Source of Contamination

Overall 56% (18/32) of samples near water pipes were positive for viruses: enteroviruses, Norwalk, and Hepatitis A virus (Karim et al. 2003, *JAWWA*)





Cryptosporidium

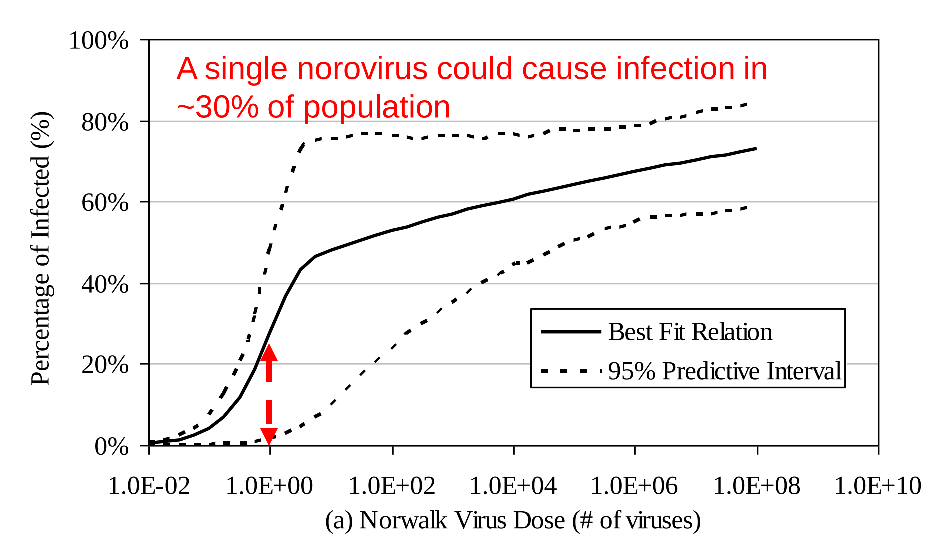
Sewage Pathogen Levels

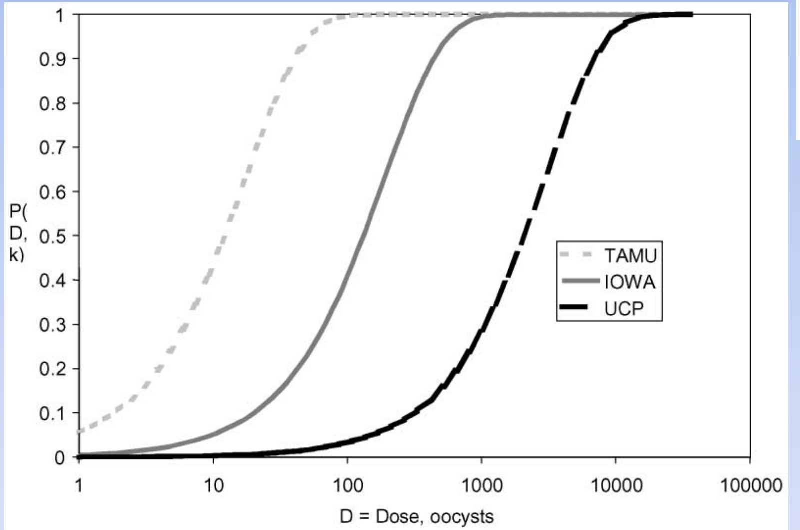
- **Meta-analysis of occurrence levels in literature**

Pathogens/Indicator	Geometric Mean	$Q_{0.025}$	Median	$Q_{0.0975}$
Cryptosporidium	2.58×10^{1}	2.03×10^{-3}	2.84×10^{1}	2.41×10^{5}
E coli O157:H7	3.19×10^{3}	1.57×10^{-7}	5.21×10^{3}	2.47×10^{11}
Norovirus	1.59×10^{4}	1.98×10^{-4}	2.38×10^{4}	1.39×10^{10}

Pathogen Infectivity

1. Virus may be highly infectious.
2. Bacteria and protozoa: relatively less infectious. The infection risk for one *Cryptosporidium* oocyst was 0.028.



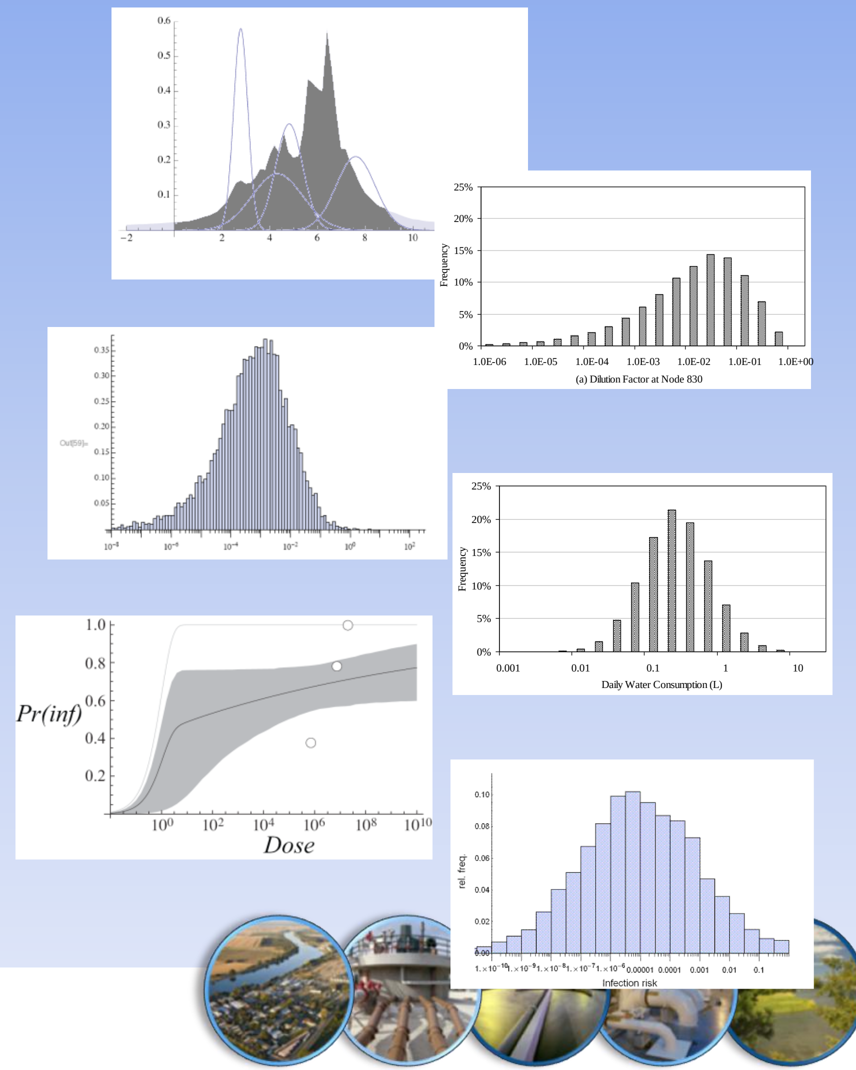


Dose response relation of Norwalk virus (norovirus) and Cryptosporidium. Norwalk virus (norovirus) dose response was obtained from combined dispersed (shown) and aggregated (not shown) virus data (Teunis et al., 2008). The dose response relationship of Cryptosporidium (Messner et al., 2001) was used, which included three different Cryptosporidium parvum isolates (IOWA, TAMU, and UCP).

Development of Quantitative Microbial Risk Assessment (QMRA)

Monte-Carlo Simulation (Mathematica 8.0)

1. External virus concentration
2. Main break and depressurization
3. Intrusion and dilution
4. Pathogen reduced by flushing and disinfection
5. Volume consumed at the 1st downstream customer
6. Dose Response
7. Risk Calculation



Task 2.2 – Disinfectant Decay and Inactivation Experiment Setup

Two disinfectants: chlorine and chloramines

Three (3) intrusion volumes: 0.01%, 0.1%, and 1%

Three (3) microbial pathogens/surrogates

- E coli (for bacteria)
- MS-2 bacteriophage (for virus)
- Bacillus spores (for protozoa)

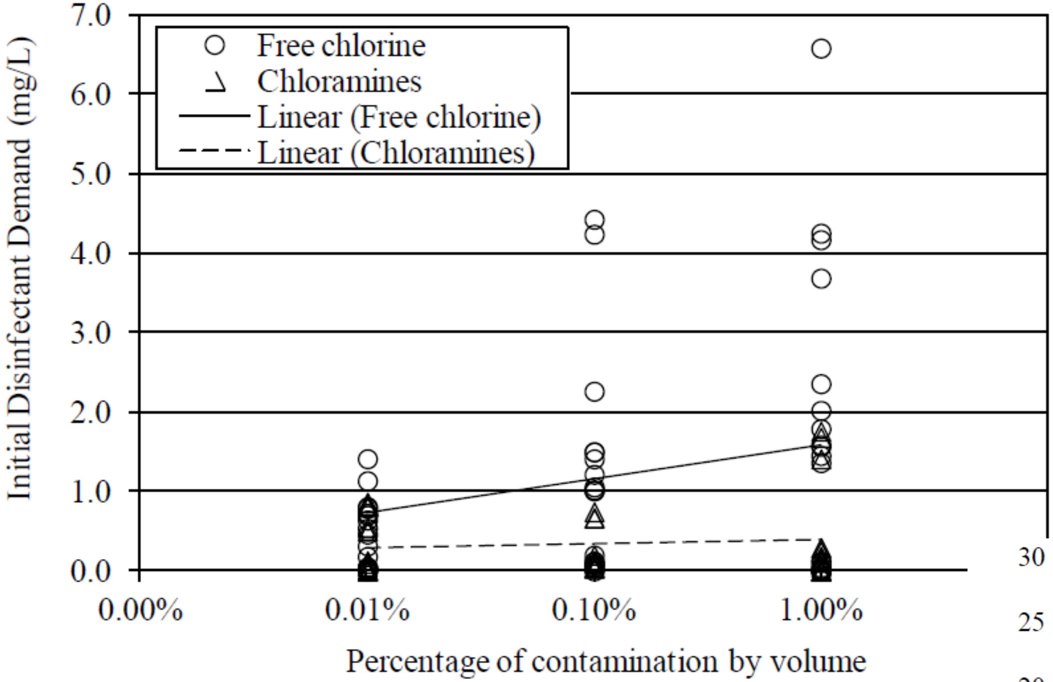
Four (4) environmental water samples

- Raw sewage
- Standing water in valve boxes
- Standing water in meter chambers
- Residual water from main break excavation pits

Three (3) reactors run in parallel at 10ºC

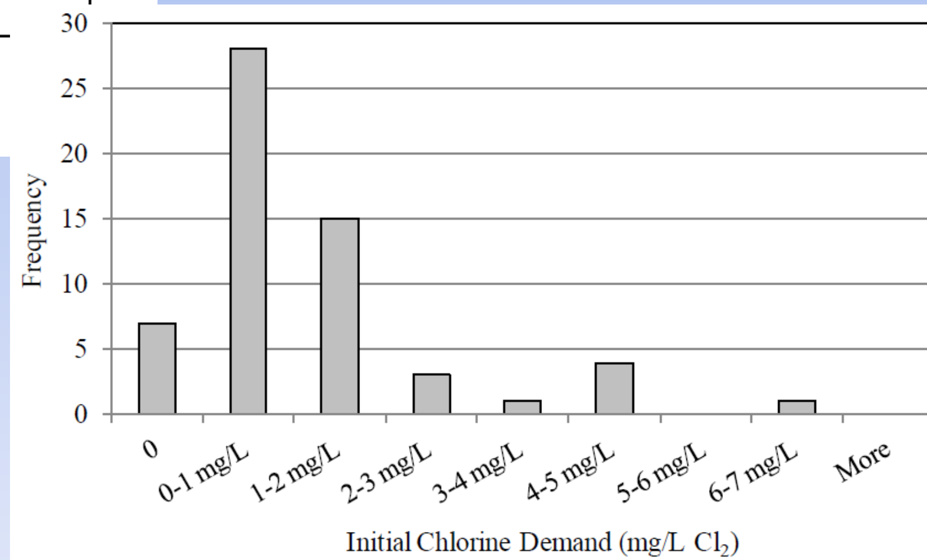
- R1 microbial control reactor
- R2 disinfectant decay control reactor
- R3 test reactor spiked with environmental water samples and microbes

Results: Disinfectant Decay



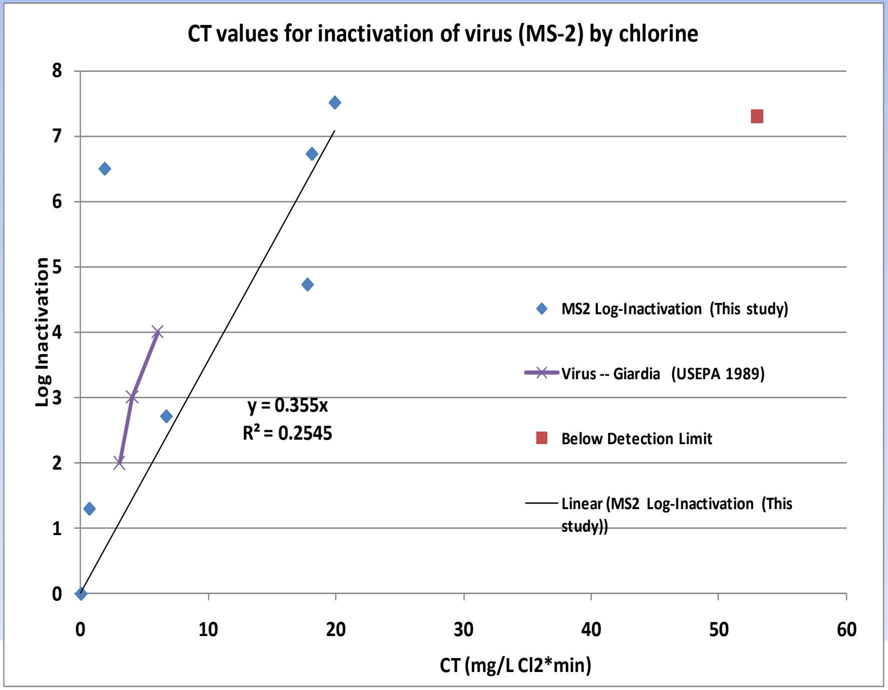
- Initial chlorine demands mostly 0-2 mg/L, up-to 7 mg/L
- Initial chloramine demands less than 1 mg/L

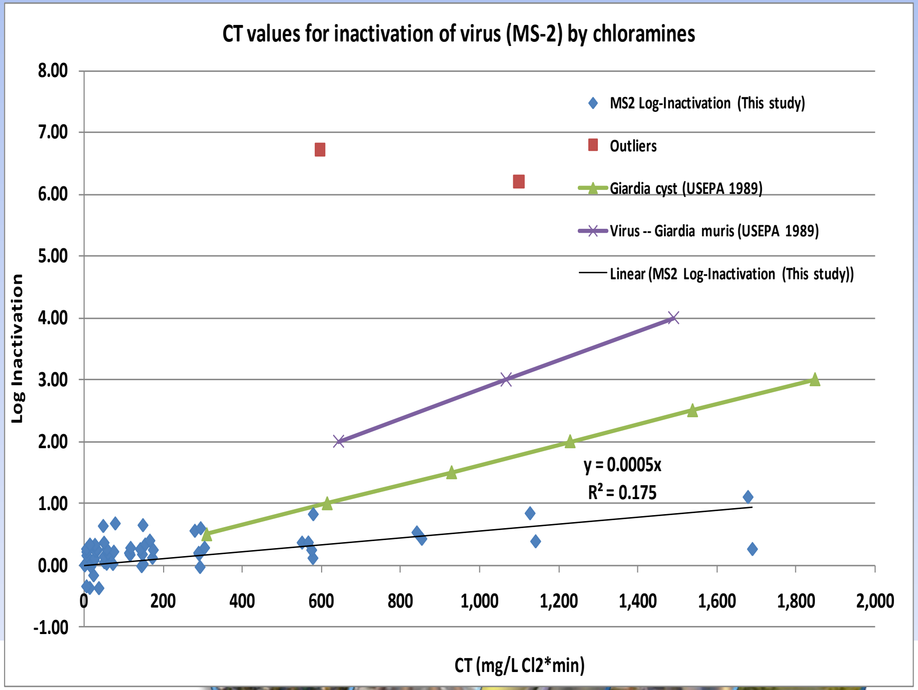
Initial chlorine residual is likely overcome by water contamination after main break depressurization, while chloramine residual may still remain.



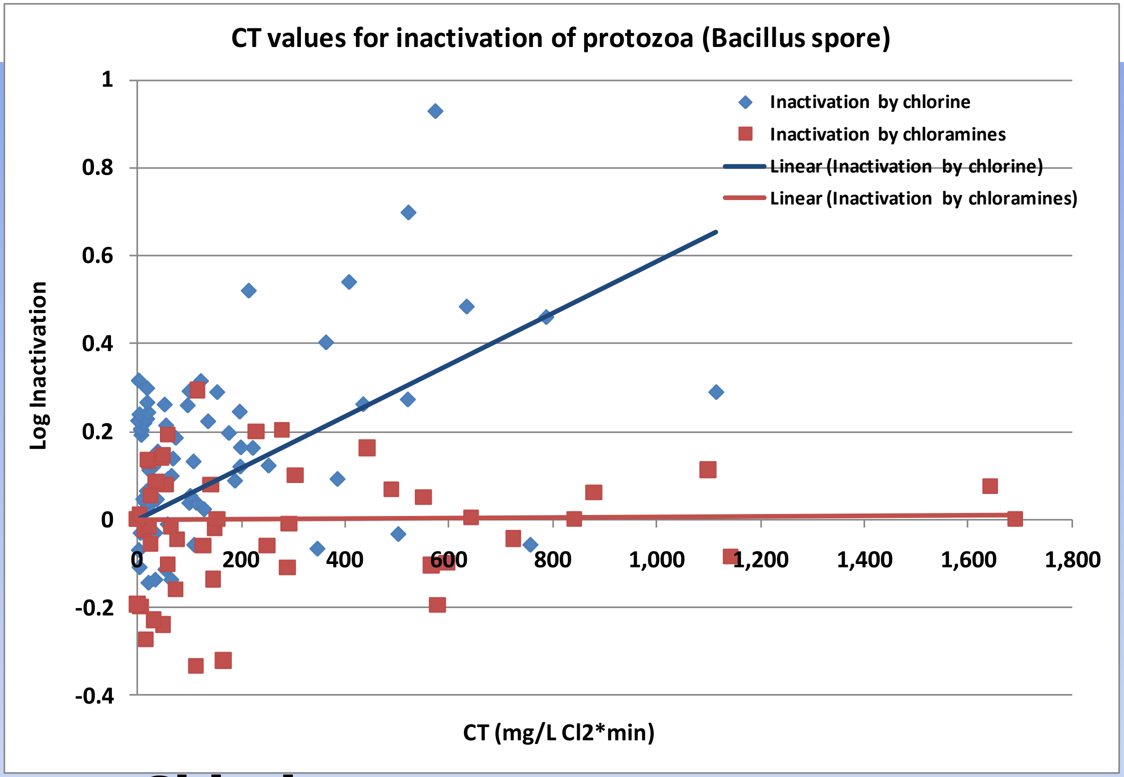
Results: MS-2 (Virus) Inactivation

- **Chlorine can effectively inactivate MS-2 virus**
  - >5-Log inactivation with a CT of 15-20 mg/L Cl_2*min
- **Chloramines cannot effectively inactivate MS-2 virus**
  - <1-Log inactivation with a CT of ~1,600 mg/L Cl_2*min





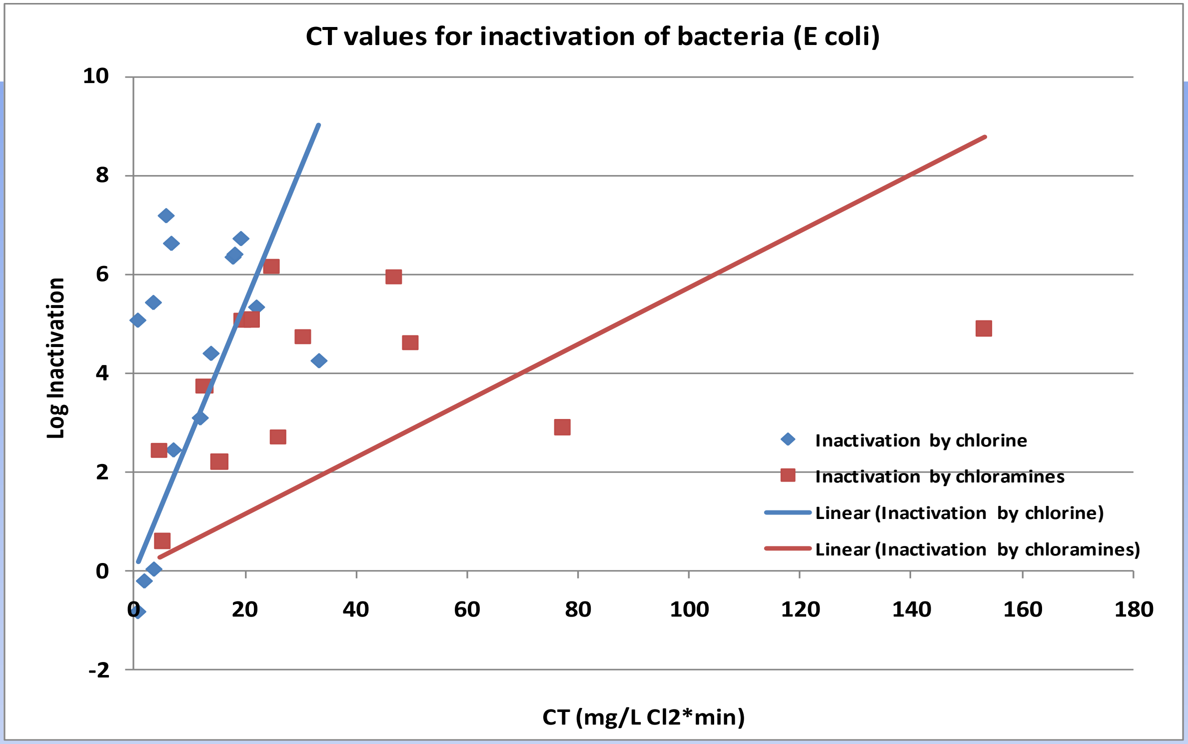
Results: Bacillus (Protozoa) Inactivation



As expected, Bacillus served as surrogate for *Cryptosporidium*, highly resistant to chlorine and chloramines.

- **Chlorine**
  - <1-Log inactivation with a CT up to 1,200 mg/L Cl_2*min
- **Chloramines**
  - No significant inactivation with a CT up to ~1,600 mg/L Cl_2*min

Results: E coli (Bacteria) Inactivation



Least disinfection-resistant compared with the other two studied microbes.

- **Chlorine**
  - >4-Log inactivation with a CT <20 mg/L Cl_2*min
- **Chloramines**
  - >4-Log inactivation with a CT 20-160 mg/L Cl_2*min

Risk Model (2-4)

	Invtrusion Vol (gal)			
Diameter	0.1	1	10	100
4	0.05%	0.51%	5.11%	51.06%
6	0.02%	0.23%	2.27%	22.69%
8	0.01%	0.13%	1.28%	12.76%
10	0.01%	0.08%	0.82%	8.17%
12	0.01%	0.06%	0.57%	5.67%
16	0.00%	0.03%	0.32%	3.19%
24	0.00%	0.01%	0.14%	1.42%
36	0.00%	0.01%	0.06%	0.63%
72	0.00%	0.00%	0.02%	0.16%

(2) Intrusion Dilution

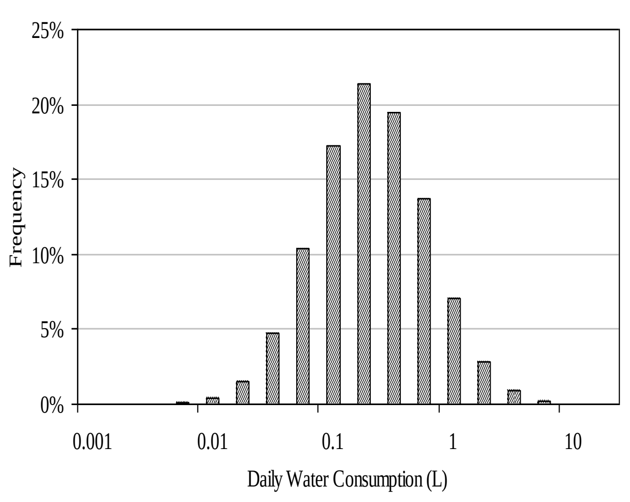
- **300 feet pipe depressurized**
- **Intrusion of 0.1 - 100 gal of sewage**
- **Dilutions of 99 to 99.99%**

(3) Pathogen Levels after Main Break Repairs

- **Removed by flushing**
- **Inactivated by disinfection**
- **Determined by lab studies shown in later slides**

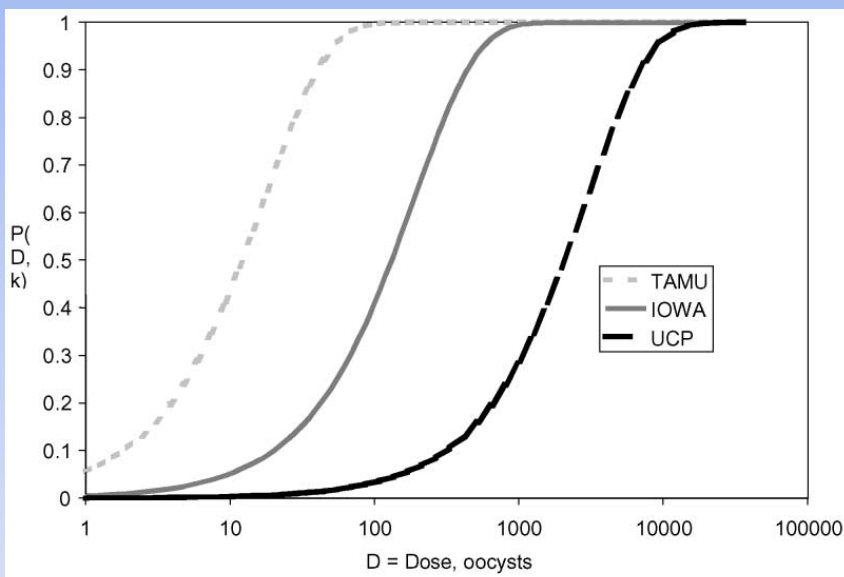
(4) Individual Water Intake

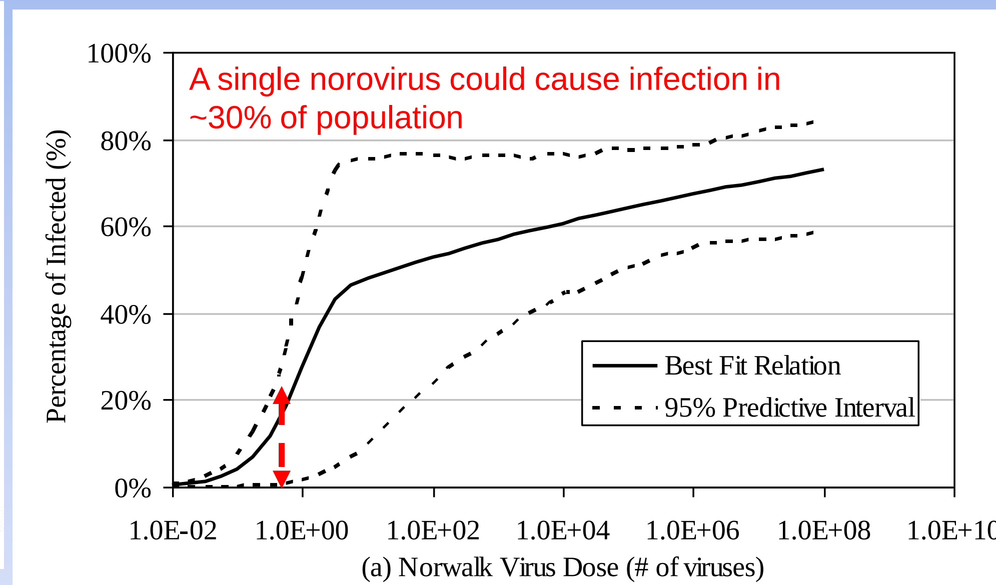
- **Unheated tap water intake from a population survey (Teunis et al. 1997)**
- **Lognormal distribution with a median water consumption of 0.18 liter**



Risk Model (5) Dose Response Models

- Collected from literature
- Human feeding studies for various pathogens
- Determined the probability of infection



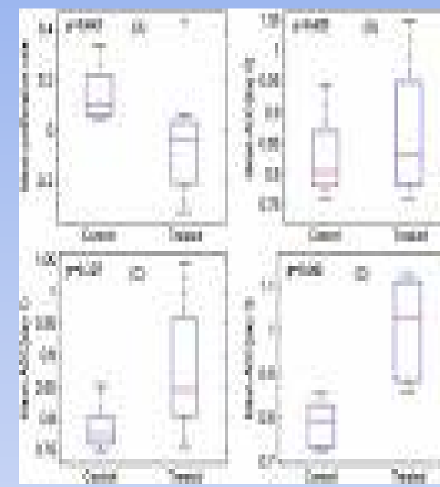


A single oocyst could cause infection in 2.8% of population

Risk Model (6)

(6) Risk Characterization

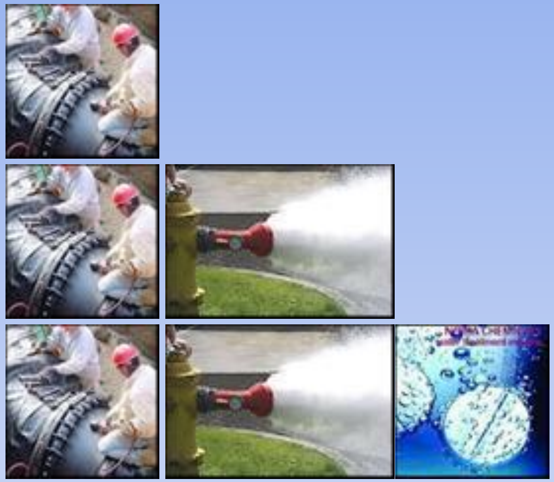
- **Monto-Carlo simulations (10,000 repetitions or more)**
- **During each repetition, random generated**
  - **External pathogen levels**
  - **Pathogen reduction by dilution, flushing, or disinfection**
  - **Individual water intake**
  - **Pathogen infectivity**



Risk Model (7)

(7) Risk Management Options

- **Baseline risk levels (dilution only)**
- **Risk levels after dilution + flushing**
- **Risk levels after dilution + flushing + disinfection**

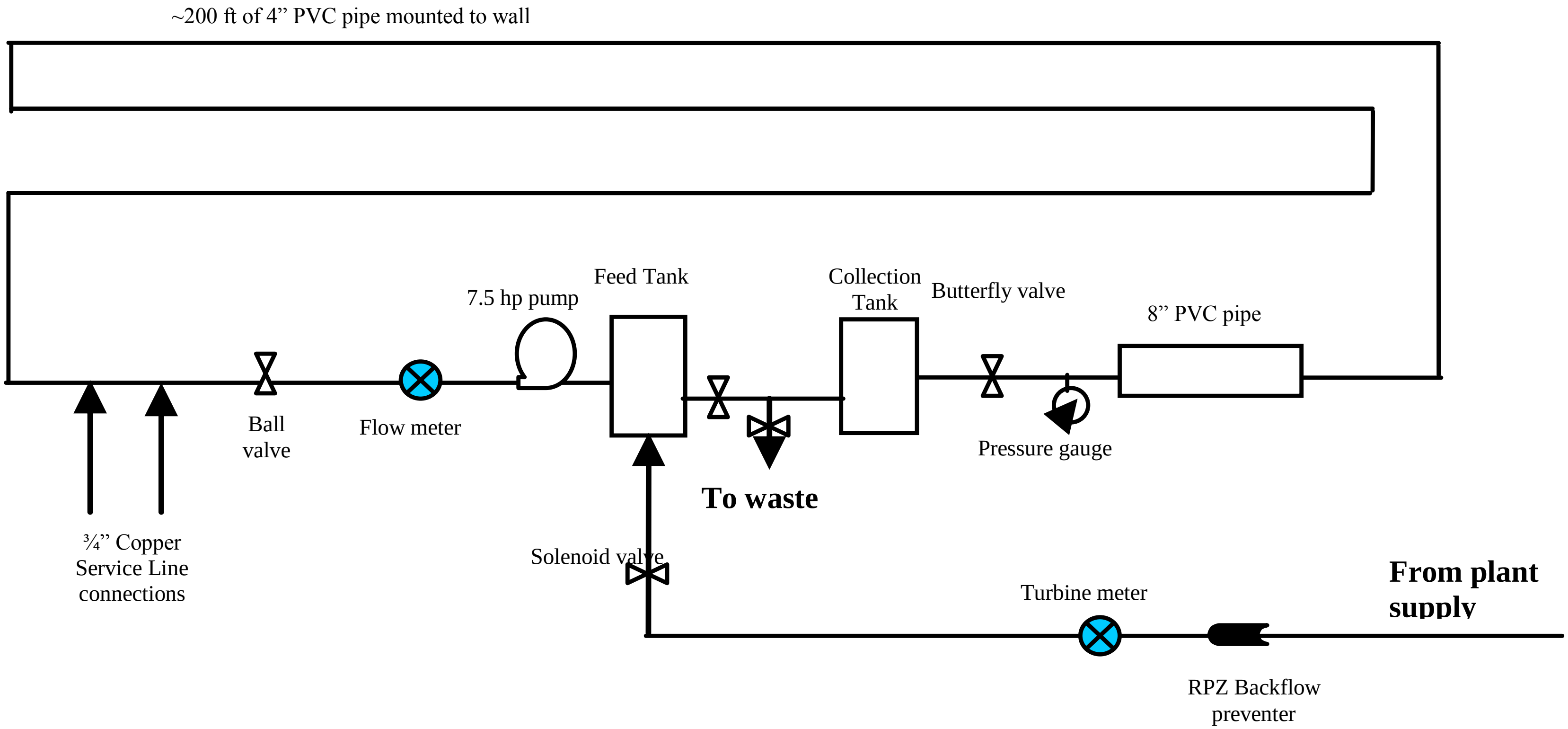


Task 2.2: Impact of Particles

- **Particle size**
  - Sands/gravels
  - Silts/clays
  - Peat
- **Impact on pathogen inactivation (4-log target)**
  - Increase CT from 15-20 mg/L-min
    - to 70 mg/L-min for sand-associated MS-2
    - to 1500 mg/L-min for peat-associated MS-2

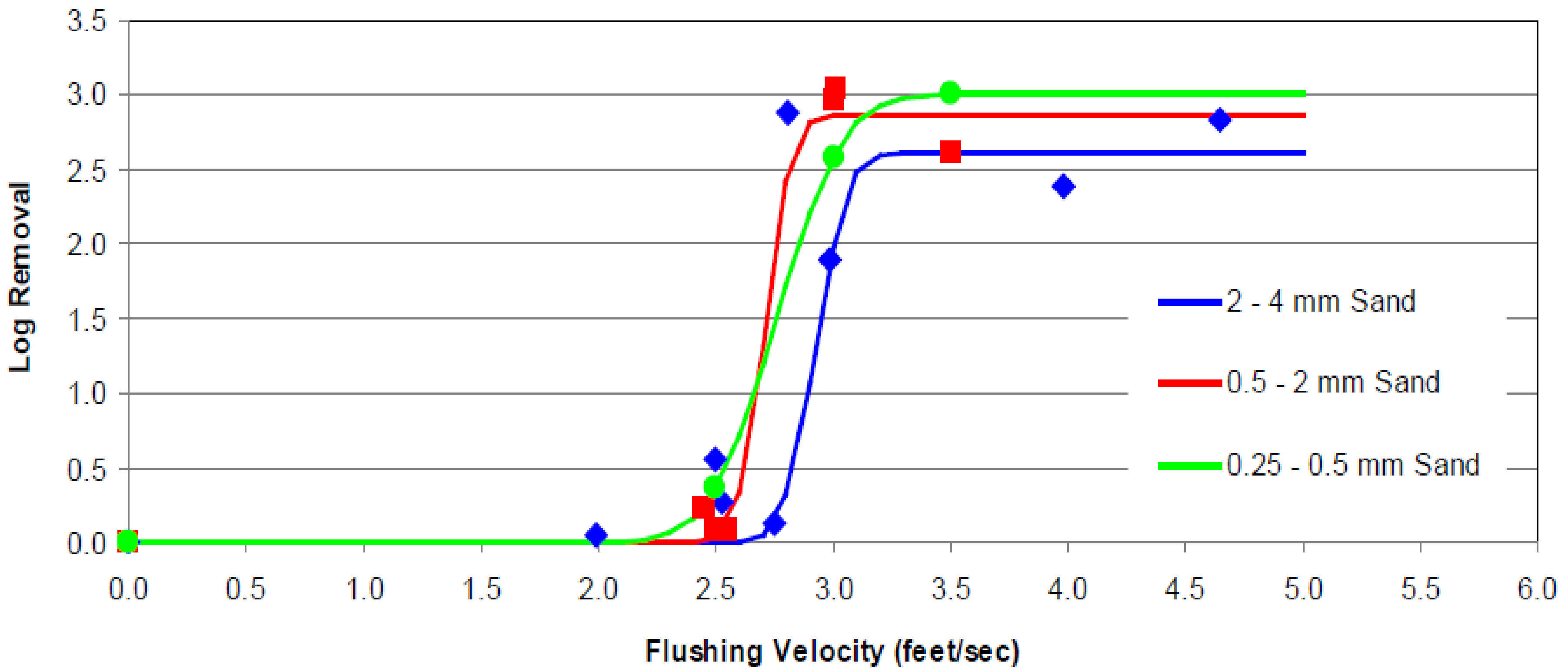
Task 2.3 – Flushing Experiment

- Evaluate flushing effectiveness on particle removal
  - Factors such as flushing velocity, duration, particle size, etc.

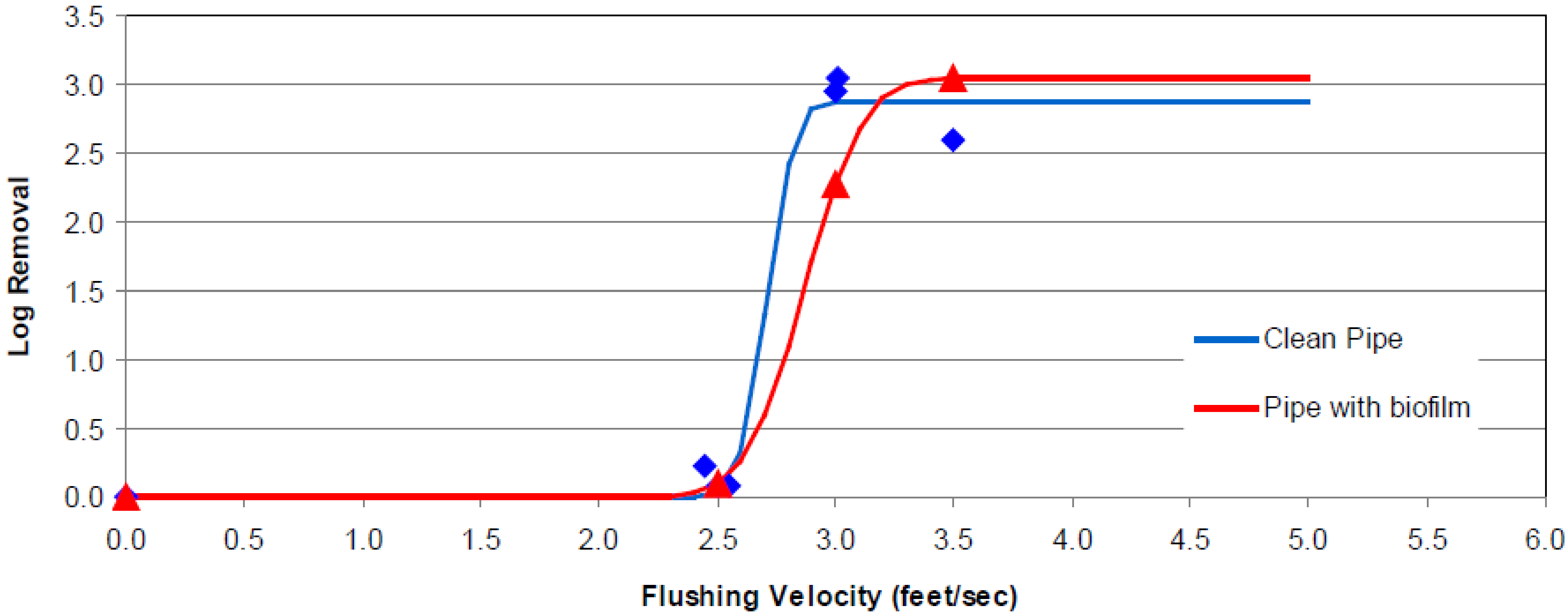


Task 2.3 – Flushing Experiment

Flushing Velocity & Sand Size

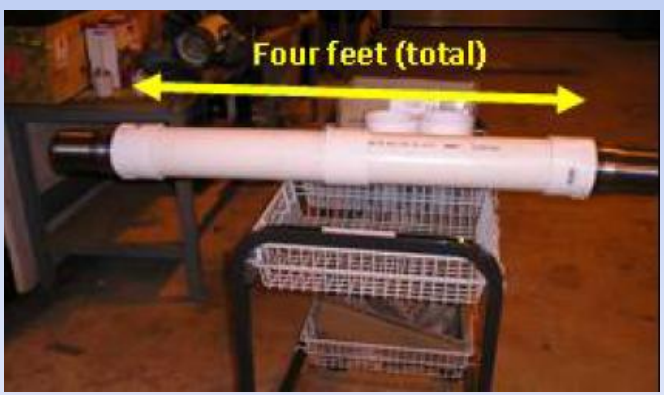


Flushing Velocity & Biofilm



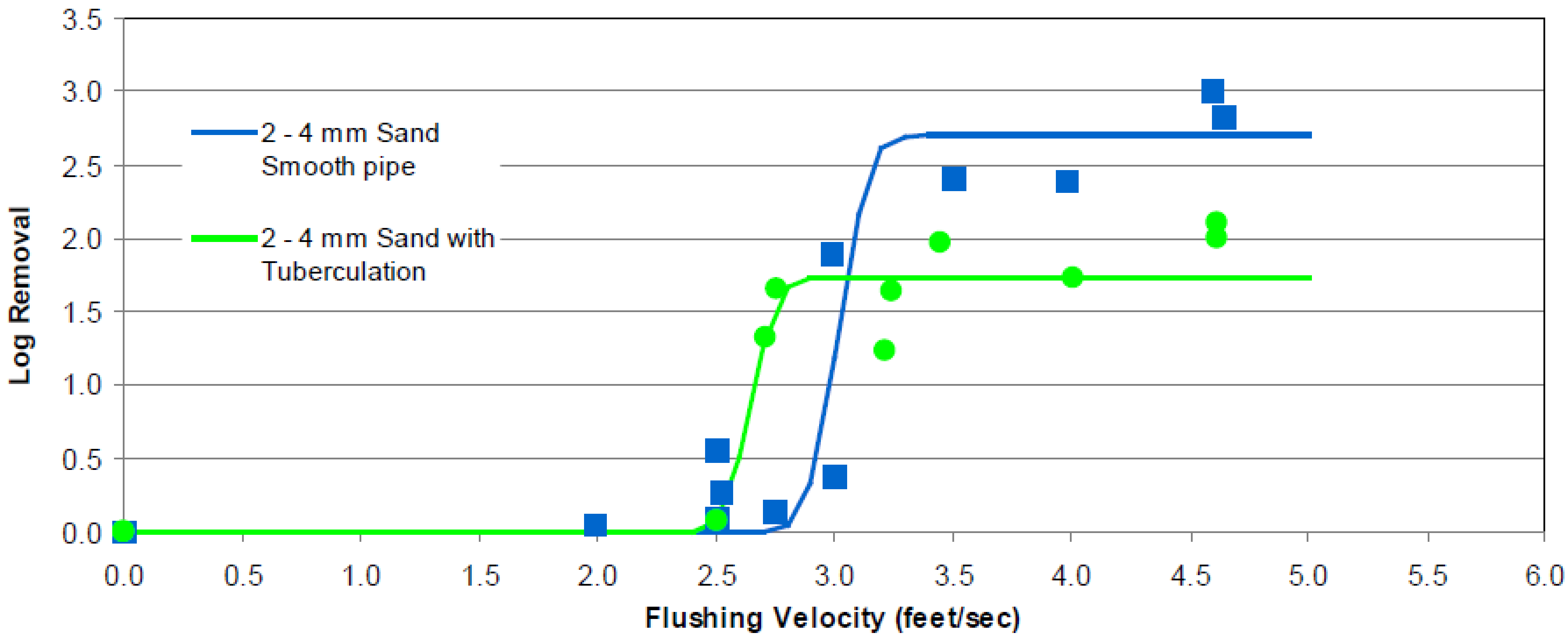
Flushing Velocity & Tuberculated Pipe

Highly tuberculated pipe model



Low to moderately tuberculated pipe model

Flushing Velocity & Tuberculated Pipe



Overall Main Break Risk Assessment (Conservative)

Intrusion of raw sewage

- Leaking sewage nearby, worst scenario (compared with pit waters)

Using sand as surrogate for flushing

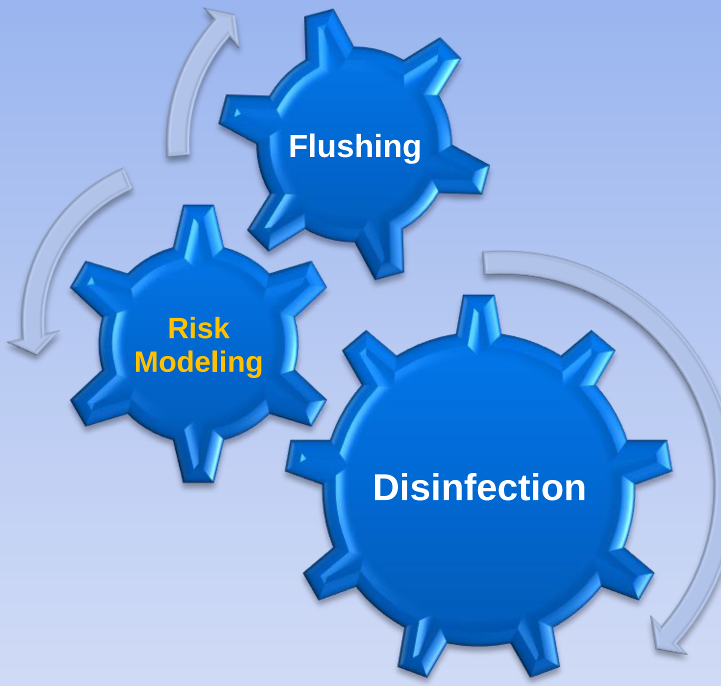
- Sand is more difficult to flush, but provides minimal shielding from disinfection
- Lighter soil particles (e.g. peat) provide most protection, but easier to flush out.

Using the *CT* of peat-attached virus for disinfection

- Sand or clay: 4-log inactivation *CT* values for free chlorine up to 92 mg/L Cl_2*min
- Peat: 4-log inactivation *CT* values for chlorine up to 1,500 mg/L Cl_2*min

Conservative Model

- Assumed worst case for flushing and for CT



Step 2 – Summary

- **Lab studies were conducted to evaluate pathogen removal efficacies by flushing and disinfection**
  - Background disinfectant residuals may either be overcome by water contamination (free chlorine) or not provide adequate inactivation of pathogens (chloramines).

- **A microbial risk model was developed to evaluate customer's infection risks after a main break and depressurization event**
  - Virus is the controlling risk (7-log reduction needed).
  - Effective flushing would remove ~3-log particles and control the *Crypto* infection risk.
  - Additional 4-log virus inactivation (disinfection) is needed to control the virus infection risk.
  - Soil particles may protect virus from disinfection and 4-log inactivation *CT* values for free chlorine increase up to 100 mg/L Cl_2*min.

Step 4: Develop Tiered Risk Management Strategy Including Multiple Barriers

- Risk Management Workshop
  - April 18-19, 2012
  - Mt. Laurel, NJ at American Water
  - 30 participants from operating utilities, regulatory agencies, and the project team
- Develop a Tiered Risk Management Strategy
- Document the Best Management Practices

Workshop Goals

1. Confirm the applicability of the risk model
2. Confirm the risk model input parameters (e.g., disinfectant concentration, flushing velocity)
3. Identify field activities for the next phase of the study
4. Discuss the applicability of this study as the technical basis for future revision of AWWA Standard C651

Key Results

- Developed four categories of main breaks
- Developed proposed response actions (procedures) for each type of break
- Identified field study objectives

Main Break Categories

Type I Break	Type II Break	Type III Break	Type IV Break
• Positive pressure maintained during break	• Positive pressure maintained during break	• Loss of pressure at break site/ depressurization elsewhere in system	• Loss of pressure at break site/ depressurization elsewhere in system
• Pressure maintained during repair	• Pressure maintained until break exposed	• Partially or un-controlled shutdown	• Widespread depressurization
• No signs of contamination intrusion	• No signs of contamination intrusion	• Possible contamination intrusion	• Possible/ actual contamination intrusion

Type I Main Break Procedures

Positive Pressure Maintain during Break and Repair

Procedures
• Excavate to below break
• Maintain pit water level below break
• Repair under pressure
• Disinfect repair parts
• Check residual disinfectant level in distribution system
• No Boil Water Advisory (BWA)
• No bacteriological samples

Type II Main Break Procedures

DRAFT

Positive Pressure Maintain during Break but shutdown needed

Procedures
• Excavate to below break
• Maintain pit water level below break
• Controlled shutdown
• Disinfect repair parts
• Conduct low velocity flush
• Check residual disinfectant level in distribution system
• No Boil Water Advisory (BWA)
• No bacteriological samples

Type III Main Break Procedures

Loss of Pressure during Break

Procedures
• Uncontrolled shutdown
• Document possible contamination
• Disinfect repair parts
• Conduct scour flush (3 ft/sec min)
• Conduct slug chlorination (Ct of 100 e.g., 5mg/L for 20 min)
• Check residual disinfectant level in distribution system
• No Boil Water Advisory (BWA)*
• No bacteriological samples*

**Based on risk model results, application of the proposed procedures, and acceptance by regulatory agencies*

Type IV Main Break Procedures

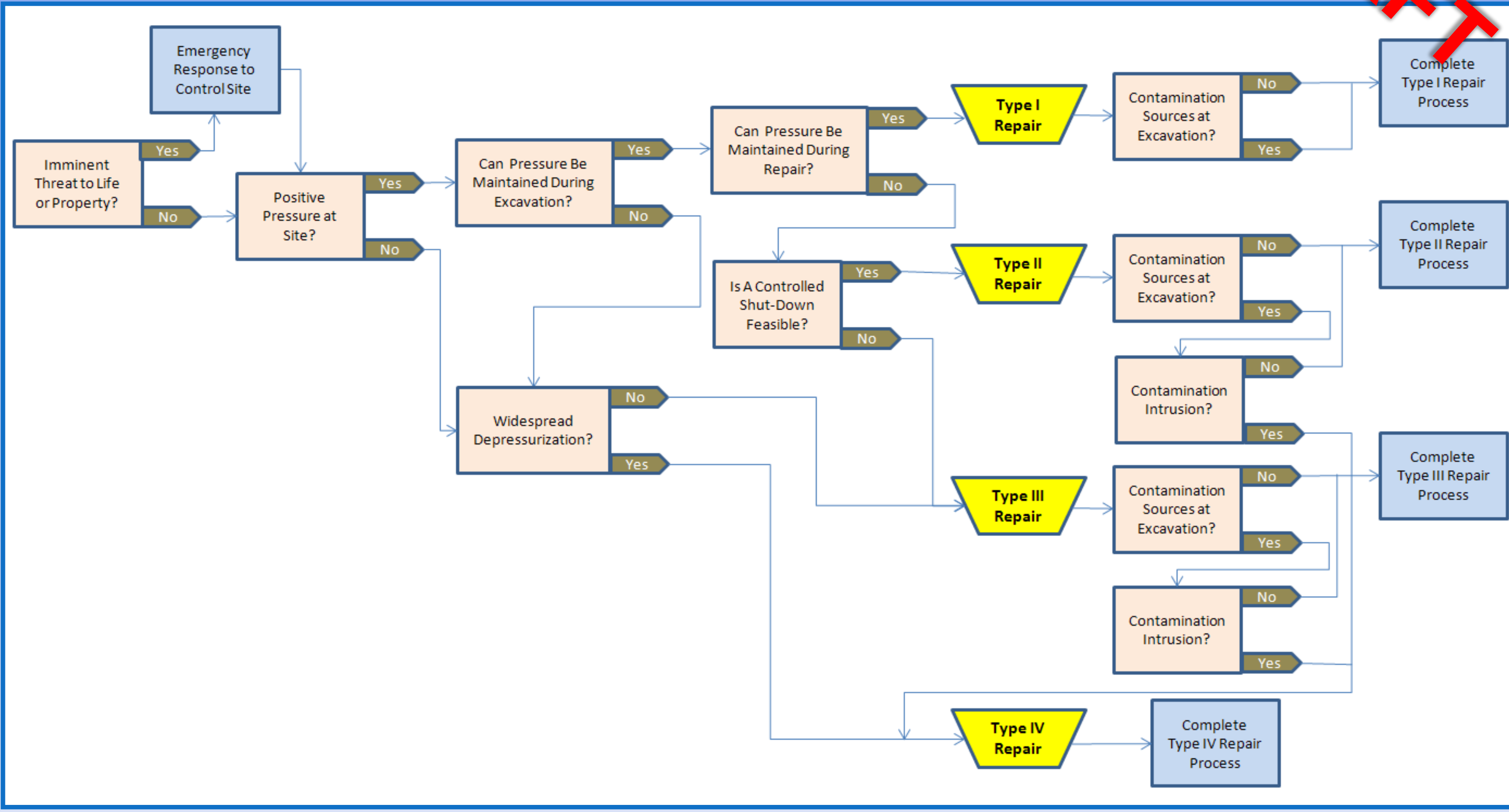
Loss of Pressure during Break and system depressurization

Procedures
• Catastrophic failure response
• Document possible contamination
• Shut-off customer services in affected area
• Disinfect repair parts
• Conduct scour flush (3 ft/sec min)
• Conduct slug chlorination (Ct of 100)
• Instruct customers to flush premise plumbing upon return to service
• Check residual disinfectant level in distribution system
• Issue BWA/ Boil Water Order
• Bacteriological sampling required

Expected Frequency of Break Type

Estimated % of Total Breaks			
Type I	Type II	Type III	Type IV
50%	35%	10%	<5%

Main Break Triage



Back to Step 3 - Identify/Pilot Test Field & Monitoring

- Identify field risk reduction strategies
- Develop monitoring program to confirm disinfectant efficacy
- Beta-test sanitation control strategies

- To become widely used, field procedures need to be:
  - Effective – practical – economical – acceptable to regulators

Field Application of Triage Approaches

Documentation & Evaluation Form

Field Study Procedure: *Pressure Maintenance and Verification*

Name of Utility: City of Bellevue Crew Chief Name: Rick G.

Date of Break: ____9.20.2012_______ Time:___10:00 am__ X A.M. ❑

GENERAL:

Pipe Diameter: ____6"____ Inches Pipe Material: ___Asbestos Concrete (AC)____

Identify nature of break (Pleas

❑ Circumferential

❑ Sleeve

❑ Other:__________

Identify the cause of break: Pl

❑ Water Hammer (Surge) ❑ Defective Pipe ❑ Deterioration

❑ Corrosion ❑ Improper Bedding ❑ Operating Pressure

❑ Temperature Change ❑ Differential Settlement ❑ Contractor

❑ Unknown X Other: Appeared to be hit during another past utility installation

FIELD PROCEDURE VERIFICATION & MONITORING DATA

Was the repair completed while maintaining positive pressure in the pipe? Yes _X_ No ___

Documentation & Evaluation Form

Field Study Procedure: *Field Monitoring for Chlorine Residuals*

Name of Utility: City of Bellevue Crew Chief Name: Michael H.

Date of Break: ___9.7.2012___ Time:___2:45__ X P.M.

And Back to Step 4

Based on Field Testing of Proposed Triage Response:

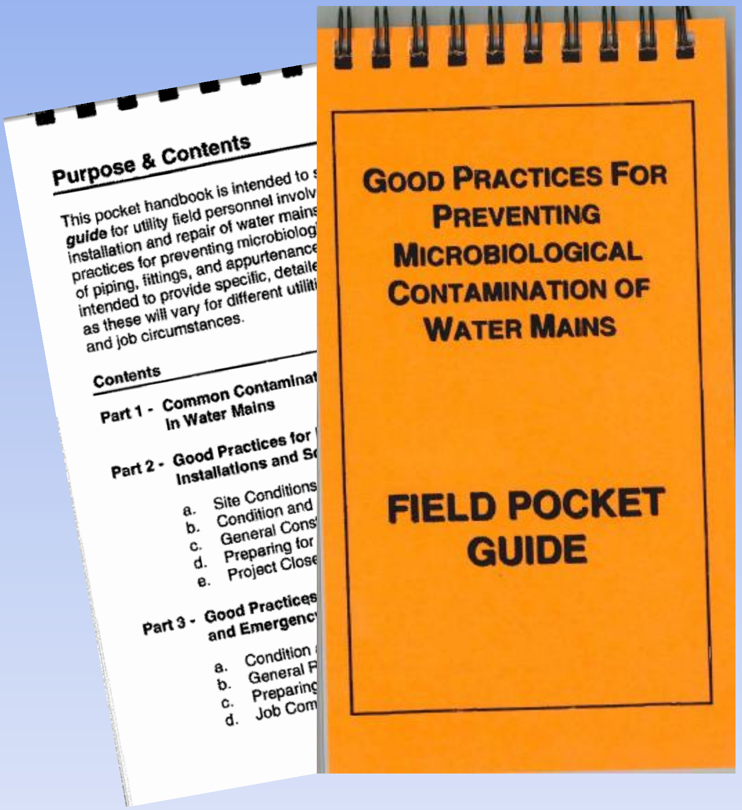
1. Risk Flow Chart
2. Documentation
    1. Maintaining Pressure during Repair
    2. Slug Disinfection vs Run-to-Ambient
    3. Field Monitoring (Chlorine)

Step 5 Work Products

Project Report (2013)

- Example SOP's of Best Practices
- Surveys & Case Studies
- Draft & Final Report

Pocket Guide Update



Project Benefits

- Technical Basis for New / Revised AWWA Standard
  - AWWA-Updating the AWWA Standards to improve clarity,
  - Coordination with Revised Total Colifom Rule.
- Water Utilities-Revising existing water utility guidelines and practices to improve sanitation during main break repair, and
- Regulatory Agencies-Revising regulatory requirements to better match the Risk with the Response.

Effective Microbial Control Strategies for Main Breaks and Depressurization

QUESTIONS

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