Consultants in Environmental, Engineering, and IT Services
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Three Years After Walkerton:
What have we learned?

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a division of Conestoga-Rovers & Associates Ltd.

Key Considerations for an Action Plan

- Who is first contacted?
- What will the chain of command be?
- Who will organize the responding actions taken to investigate/mitigate outbreak?

Information Required for Action Plan

- What organism is causing the outbreak?
  - Bacteria, Virus, Protozoa
- Is it a continual infection/re-infection, or has the infection passed?
- Average infection period of target organism is integral to Action Plan

Information Required for Action Plan

- Exhibition of symptoms in community post-infection:
  - Virus 10-14 days
  - Bacteria 2-6 days
  - Protozoa 1 - 2 weeks

Information Required for Action Plan

- What is required of the target organism to generate infection?
  - *Salmonella* 100 000 cells
  - *E. coli* O157:H7 100 cells
  - *Cryptosporidium* 10-100 cells

Other waterbourne pathogens

Bacteria

- Campylobacter
- Shigella
- Salmonella
- Vibrio cholera
- Yersinia enterocolitica

Protozoa

- Cryptosporidium
- Giardia

Viruses

- Adenovirus, Enteroviruses, Hepatitis A, Norwalk, Reovirus, Rotavirus, Coxsackie

Information Required for Action Plan

- Is the water to blame for the outbreak?
- Is the pathogenic microorganism continuing to infect people consuming the water?
- Careful review of recent & historical data for distribution system and water treatment plant

Where is the contamination site?

- Is the source(s) and site(s) of contamination known?
  - Water treatment plant
  - Distribution system
- What activities at the water treatment plant and in the distribution system may have contributed to the contamination event(s)?

Where is the contamination site?

- Is this a water treatment plant/raw intake problem or a distribution system problem?

Action Plan Development

- Boil Water Advisory is put in place
- Prioritize the potential sites of contamination
  1. raw water
  2. water treatment process failure
  3. distribution system infiltration/water main failure

Raw Water Assessment

- Ground water or Surface water?
- Review historical data on integrity of source water
- Recent weather events - heavy rainfall, storm event, runoff potential

Water Treatment Plant Assessment

- Address disinfection performance at time of suspected outbreak
- Address any process concerns
  - disinfectant dispensing equipment
  - reduction of contact time
  - turbidity breakthrough/loss of disinfectant residual
  - Filter performance/operation

Mitigation of Treatment Plant/Distribution System

- ↑ rate of chlorination to achieve 5.0 mg/L Free Cl in the extremities of distribution system
- ↓ Free Cl to 2.0 mg/L after 10-14 days at 5.0 mg/L
- Areas of older mains (cast iron pipe) may lose integrity, due to elevated Free Cl residuals * Be alert for unusual pressure ↓ or water main breaks

Mitigation of Water Contamination

- Following a close evaluation of system, target contamination site(s) are identified, and mitigation steps should be initiated

Walkerton Case Study

- Objective of Mitigation Attempt:
  1. Ensure that the source(s) of contamination were eliminated.
  2. Ensure that *Campylobacter jejuni* *and* *Escherichia coli* O157:H7 are destroyed in the wells and the distribution system.

Soon after the investigation began, Well 5 was considered to have been the major source of contamination of the distribution system based on a number of factors:

1. Shallow well located at southwest perimeter of town, located near a farm with cattle.

2. Strongly suspected to have aquifer and /or well affected by surface water.

3. Presence of coliforms and *E. coli* detected in late May and early June in the well and continued to be present in large volume samples 1 - 5 litre.

Walkerton Case Study

Conclusion early in the investigation that the distribution system was impacted by soil and surface water contamination.

Speculated that during rainfall events, which resulted in ponding when Well 5 was pumping, soil microbes and nutrients were pumped throughout distribution system.

Walkerton Case Study

Possible Sources of Contamination of the Municipal Wells and the Distribution System

Walkerton Case Study

Agricultural Sources:

Runoff from manure spreading.

Manure piles located on stream banks.

Liquid manure applied to fields that are tiled.

Walkerton Case Study

Septic tank failure.

Inadequately digested sludge spread on land where thin surface soils overlay limestone bedrock.

Walkerton Case Study

Cattle watering in streams

Walkerton Case Study

Urban Sources:

- Intrusion of sewage into water mains
- New mains improperly disinfected
- Water main repair performed inappropriately

Walkerton Case Study

Abandoned wells remained connected to the system

Private wells directly connected to the municipal system (e.g., shallow dug well was directly connected with pump capable of producing water pressures significantly greater than the municipal main pressure)

Walkerton Case Study

The surface of the well water contained hundreds of "earwigs"

The water contained 40,000 coliforms per 100 mL and few *E. coli*

Walkerton Case Study

Cisterns, which were used as a source of soft water, were commonly found to be connected to the municipal water supply

Cistern water has the potential of being highly contaminated by bacteria, viruses and parasites

Walkerton Case Study

Assessed levels of coliform and *E. coli* at multiple sites of system and include source wells.

Assessed heterotrophic bacterial populations and aerobic spore-forming bacteria.

Walkerton Case Study

Aerobic spore-forming bacteria such as *Bacillus* species included in microbial investigation

- Are naturally found in soil.
- Very resistant to free chlorine.
- Not naturally found in groundwater.
- Serve primarily as indicators of disinfection efficiency beyond the presence/absence of most coliforms and *E. coli.*
- Recovery from groundwater suggests surface contamination.

Walkerton Case Study

Compared free chlorine to reductions of coliforms, *E. coli*, heterotrophic and anaerobic spore-forming bacteria.

Increases and decreases in chlorination may result in temporary coliform detections.Caused by biofilm sloughing from walls of watermains.

Walkerton Case Study

Distribution system was comprised of approximately 40 km of water mains.

Watermain materials consisted primarily of iron and PVC but also included some polyethylene and copper.

Services were galvanized and lead.

Action Plan: Rehabilitation

- Divide the distribution system into segments
- Identify a flushing and/or swabbing program for each segment
- Notify people in the area of water shut-off times
  - List in the newspaper & on public radio
  - Large water users affected by these shut-offs require notice 1-2 weeks in advance of rehab efforts

Action Plan: Rehabilitation

- Attack distribution system with multiple crews to facilitate timely rehabilitation efforts
- Follow a swabbing/superchlorination dose, pushing 200-300 mg/L total chlorine
- High-pressure flushing
  - valve off water pressure down to streets to achieve maximum pressure

Walkerton Case Study

Removal of *E. coli*, *E. coli* O157:H7 and *Campylobacter jejuni* from Walkerton distribution pipe biofilm by swabbing and chlorine disinfection

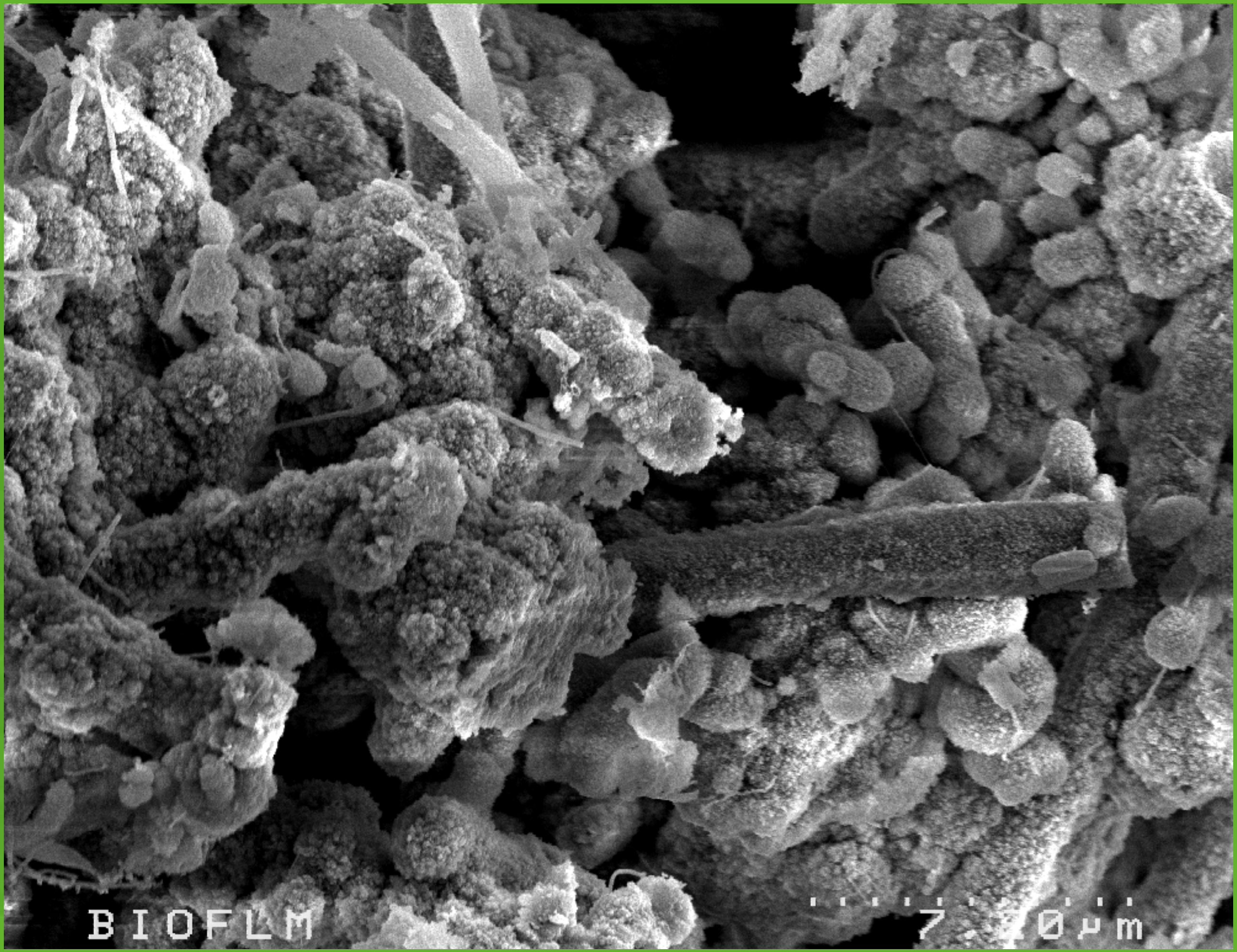
Walkerton Case Study
Microbial testing & consulting

Determine the source of contamination
- environmental and distribution system samples
- raw water and well zone testing

Disinfection of the distribution system
- disinfection protocols for mains and service lines
- testing distribution system samples
  - water and biofilm
- biofilm study

Biofilm

- Attachment of cells from the aqueous phase onto solid surfaces
- Growth and production of extracellular material
- Many types of bacteria involved in biofilm formation
  - Common type in distribution systems are iron-oxidizers (*Leptothrix*, *Gallionella*)
- Initial colonizers are resistant to chlorine
- Other bacteria can attach to established biofilm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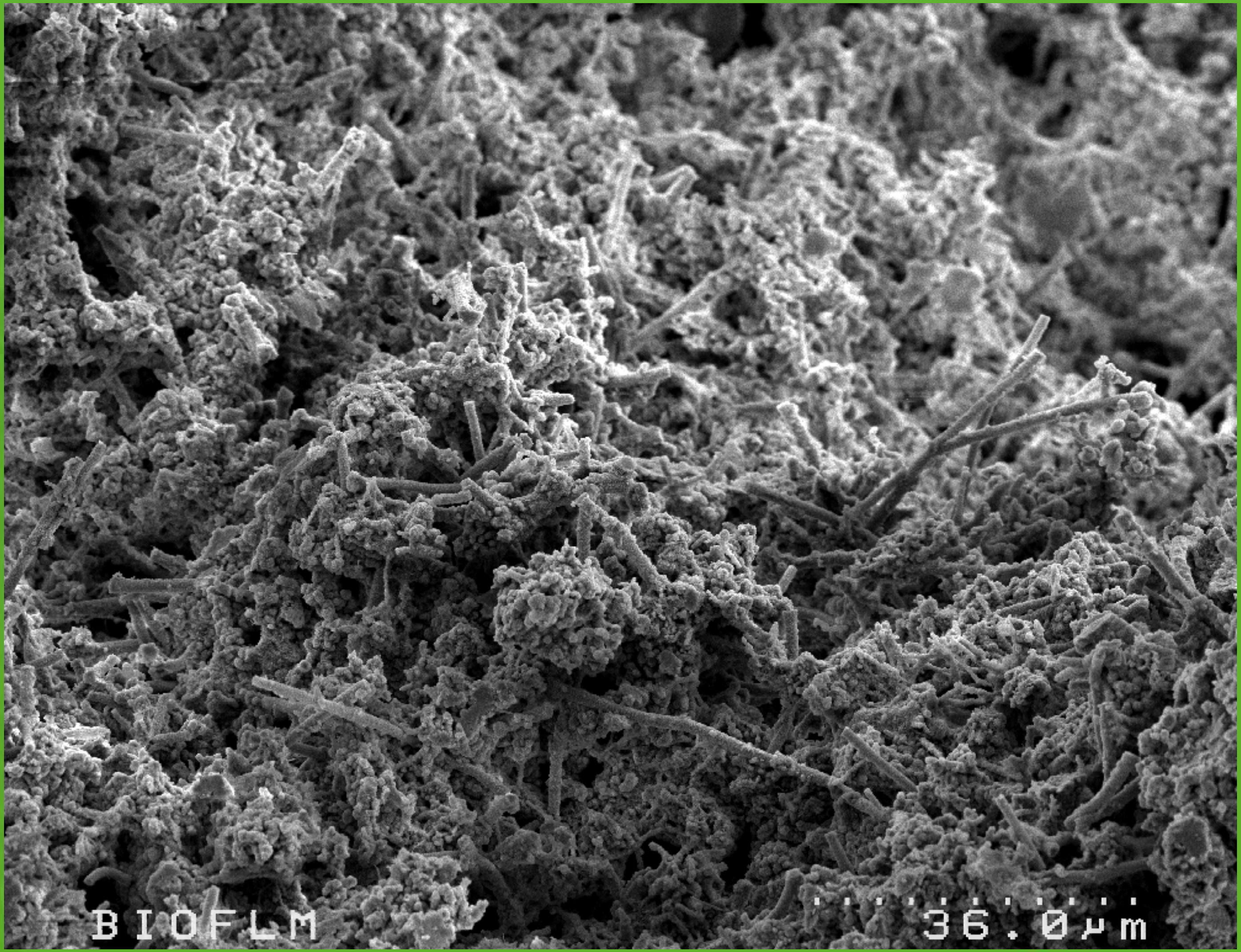
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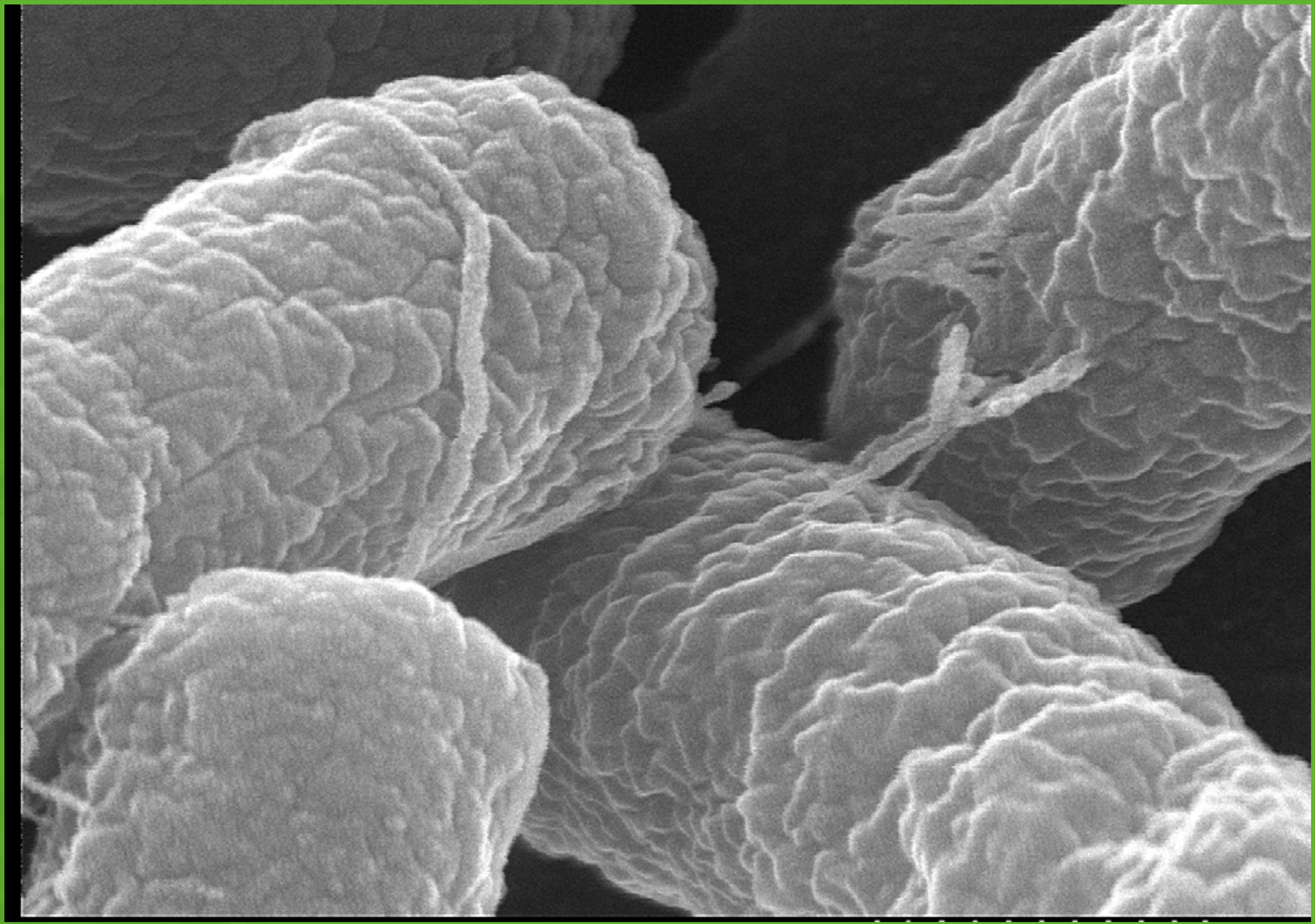


Biofilm problems in distribution systems

- Pipe corrosion
- Flow restrictions
- Requirement for increased disinfectant
- Taste and odour production
- Protection from disinfection of microbial pathogens and water quality indicators (coliforms, *E. coli*, HPC)

Control of biofilm formation

- Maintain disinfectant concentration
- Type of disinfectant used
- Pipe material
- Reduce nutrient/microbial concentrations entering the system
- Mechanical cleaning

Action Plan: Rehabilitation

- High pressure flushing
  - Problems encountered:
    - Not enough pressure: may require additional portable pumps to increase pressure
    - Small 6” pipes may have reduced ID of 2-3”, due to corrosion and biofilm, affecting swabbing/flushing and may require some main replacement

Rehabilitation of the Walkerton distribution system

- Most bacterial pathogens can be killed by chlorine
- Initial response to contamination event was to flush system with 5 mg/L free chlorine
- Problem = many older pipes in Walkerton contained extensive biofilm formation
- Attachment of bacterial pathogens to particulate matter and biofilm can protect them from disinfectants

Pressurized Chlorine Tank

Swab dispenser attached to fire hydrant

6 inch cast iron distribution pipes

not swabbed swabbed

Action Plan: Rehabilitation

- If officials directing action plan have enough time and resources, a pilot disinfection/swabbing protocol should be run, in conjunction with a biofilm study

  (as was done in Walkerton, by Dr. M. Van Dyke, GAP EnviroMicrobial Services)

Biofilm study

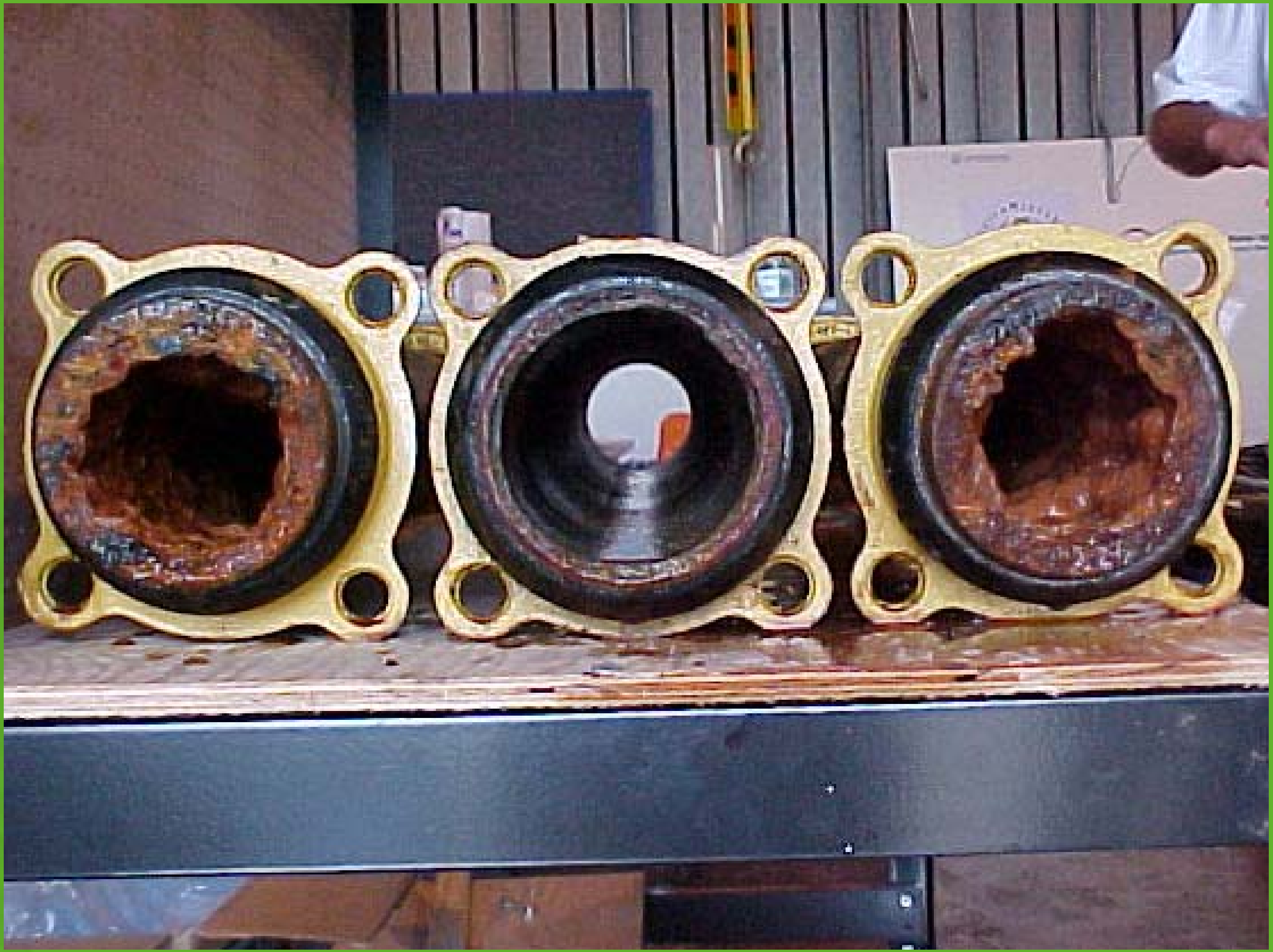
Study initiated by OCWA and GAP to determine if the disinfection program could kill pathogens introduced into pipes containing biofilm.

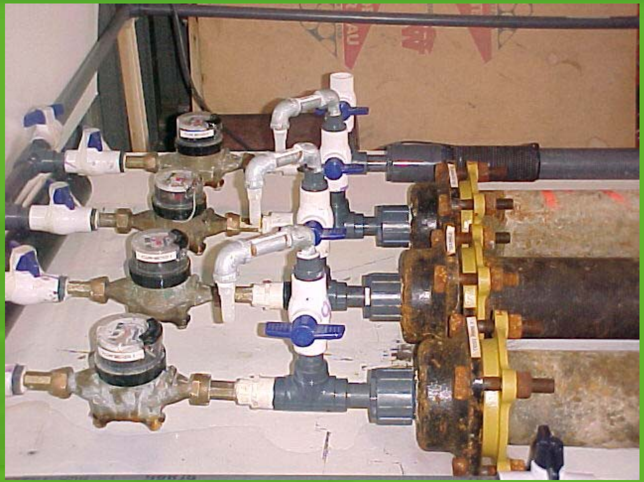
Pipe-rig apparatus constructed.

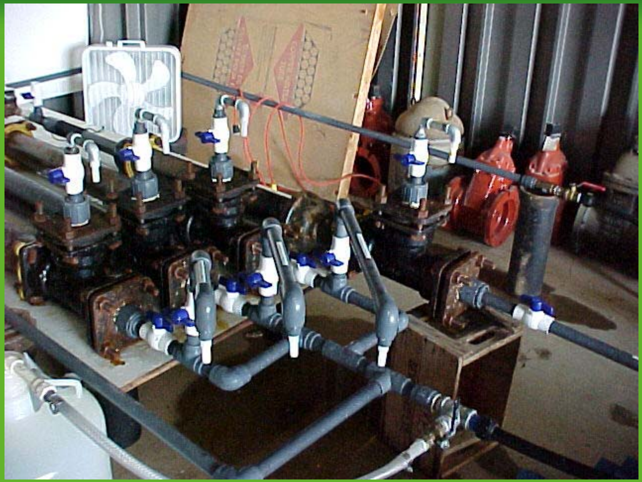
- 60 year old cast iron pipe (4 inch)
- New cast iron pipe (4 inch)

System build in maintenance shed close to well 5.

Water from well 5 passed through pipes.







Pipes inoculated with bacteria

Escherichia coli nal^{r} (1×10^5 cfu/mL)

nalidixic acid resistant, non-pathogenic

Escherichia coli O157:H7 (1×10^5 cfu/mL)

verotoxin-negative strain

Campylobacter jejuni (2×10^3 cfu/mL)

Bacteria added in sterile water from well 5.

Concentrations decreased by 2 log units after 2 days recirculation.

Pipe effluents - after inoculation

All 3 strains present in pipe effluents after 7 days of unchlorinated raw water flow.

All 3 strains absent in pipe effluents after 3 hours of water flow containing 5 mg/L chlorine.

Biofilm samples - inoculation

Unchlorinated water for 2 days

Bacteria	Biofilm enumeration (cfu/cm^2)		
	Pipe 1 (old)	Pipe 2 (new)	Pipe 3 (old)
E. coli nal^r	1×10^4	1×10^4	4×10^3
E. coli O157:H7	1×10^4	4×10^4	7×10^3
C. jejuni	4	4	1

Chlorinated water (5 mg/L) for 2 weeks

Bacteria	Biofilm enumeration (cfu/cm^2)		
	Pipe 1 (old)	Pipe 2 (new)	Pipe 3 (old)
E. coli nal^r	0.5	<0.5	<0.5
E. coli O157:H7	0.5	<0.5	<0.5
C. jejuni	<0.5	<0.5	<0.5

Biofilm samples - after inoculation

Swabbing and superchorination
  all 3 strains not detected in new and old pipes

Chlorinated water (2 mg/L) for 4 weeks
  all 3 strains not detected in new and old pipes

Heterotrophs in biofilm samples

Protocol	Biofilm enumeration (cfu/cm^2)	
	Old pipes	New pipes
Raw water for 2 weeks	7×10^6	6×10^5
After inoculation	7×10^7	3×10^7
5 mg/L chlorine for 2 weeks	1×10^6	1×10^3
Swabbing / superchlorination	1×10^4	9×10^1
2 mg/L chlorine for 4 weeks	1×10^5	1×10^2

Significance of Findings

potential for indicators and pathogens to be trapped in biofilm

swabbing/flushing important to maintain distribution pipes.

groundwater impacted by surface water assessments

proper sampling and treatment program is critical to maintaining safe water supply

Action Plan: Rehabilitation

- Success of Rehabilitation efforts measured by:
  - microbial parameters
    - Coliforms
    - HPCs
    - Total Aerobic Sporeformers (were used in Walkerton rehabilitation effort)

Summary

- Risk assessment of consuming water from a distribution contaminated with waterborne pathogens is considered moderate to high by insurance companies in Canada
- Medical officers of health are cautious in raising Boil Water Advisory Orders
- Insurance companies in Canada and USA have little confidence in drinking water quality, which will affect us all...