

CHLORINE RESIDUALS IN THE DISTRIBUTION SYSTEM

("SECONDARY" DISINFECTION?)

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John Rudnickas

OUTLINE

- The Microbial Threat
- Disinfection Basics
- Distribution System Vulnerability
- Protecting the Distribution System
- “Secondary” Disinfection Benefits, Limitations and Unintended Consequences
- Summary

THE MICROBIAL THREAT

- "Pathogens pose the greatest and most tangible risk to drinking water safety, making pathogen removal and disinfection the paramount concern."

Hrudey, 2004

Waterborne illness can be brought on by a single exposure.

WATERBORNE PATHOGENS

- Bacteria, Viruses and protozoa
- Examples;
 - *E. coli* O157:H7
 - Norovirus
 - *Giardia* →
 - *Cryptosporidium*



WATERBORNE PATHOGENS

Pathogen	Persistence in water	Resistance to chlorine	Relative infectivity
<i>E. coli</i> O157:H7	Moderate	Low	High
Norovirus	Long	Moderate	High
<i>Giardia</i>	Moderate	Moderate	High
<i>Cyptosporidium</i>	Long	High	High

WATERBORNE PATHOGENS

- Gastrointestinal infection due to fecal contamination is the primary concern regarding the potential presence of pathogens in drinking water
 - Human
 - Animal
 - Bird

WATERBORNE PATHOGENS

- Testing for pathogens themselves is impractical from an operational perspective
 - We rely on measurement of disinfection and particle removal efficiency for real time control
 - Testing for indicators of fecal contamination (*E. coli* primarily) provides confirmation

MICROBIAL/CHEMICAL SAFETY

- Exposure to pathogens can cause serious illness following a single exposure
- Concern over chemical contamination is generally based on long-term consumption of water exceeding maximum acceptable concentrations (MACs)
- Control of pathogen risk must never be compromised in favour of controlling risk from chemicals such as disinfection byproducts (DBPs)

THE MICROBIAL THREAT

- "Population health surveillance is insensitive and is likely blind to low-level endemic disease and all but the largest outbreaks."

Hrudey, 2004

- Endemic disease refers to the ongoing 'background' occurrence of illness in a population over time in contrast to the short peaks of disease associated with point source outbreaks.
- The absence of detectable outbreaks must not lead to complacency!

THE MICROBIAL THREAT

- A recently published study from the US has found that point-of-use water treatment reduced the incidence of gastrointestinal illness in people aged 55 years and older by 12% although the tap water supply met current US water quality standards
- The results of the study once again raise the issue of endemic waterborne disease due to pathogens in treated drinking water, and the adequacy of current methods of defining drinking water safety

Colford JM Jr, Hilton JF, Wright CC et al. (2009) American J Public Health

DISINFECTION BASICS

- Primary Disinfection:
Disinfectant applied at the source to provide destruction or inactivation of pathogenic organisms prior to the first customer
- Secondary Disinfection:
Disinfectant applied to water leaving a treatment plant to protect the distribution system
- Inactivation:
Rendering a pathogen harmless (not necessarily killing it)

DISINFECTION BASICS

Four main types of mechanisms:

1. Oxidation or rupture of cell wall, consequent cell disintegration.
2. Diffusion into cell and interference with cell activity.
3. UV disinfection: Damage of DNA and RNA to prevent cell replication.
4. Filtration: Physical removal of pathogens via size exclusion.

DISINFECTION BASICS

- Other desired functions of disinfectants
 - Minimize DBPs
 - Control zebra mussels
 - Oxidation
 - Removal of T&O, iron, manganese, colour
 - Prevent regrowth in distribution systems
 - Improve coagulation and filtration efficiency
 - Prevent algal growth – sedimentation basins and filters

DISINFECTION BASICS

- "Secondary" disinfection
 - Required by regulation in Ontario
 - Recommended by most international jurisdictions to serve as a barrier against contamination due to loss of system integrity
 - However... some international jurisdictions do not require a disinfectant residual in the distribution system (Driven by DBP concerns as well as T&O)

DISINFECTION BASICS

- "Secondary" disinfection
 - Generally achieved by maintaining a free or combined chlorine residual throughout the distribution system
 - A free chlorine residual is a powerful disinfecting agent but can also be unstable and difficult to maintain
 - Combined chlorine (monochloramine) is a much weaker disinfectant than free chlorine but this may be somewhat compensated for by its greater stability

DISTRIBUTION SYSTEM VULNERABILITY

DISTRIBUTION SYSTEM VULNERABILITY

- If appropriate disinfection requirements have been met at the source, the distribution system (including plumbing) is the final barrier to preventing waterborne disease
- The distribution system has sometimes been referred to as the “final frontier” in achieving drinking water safety

DISTRIBUTION SYSTEM VULNERABILITY

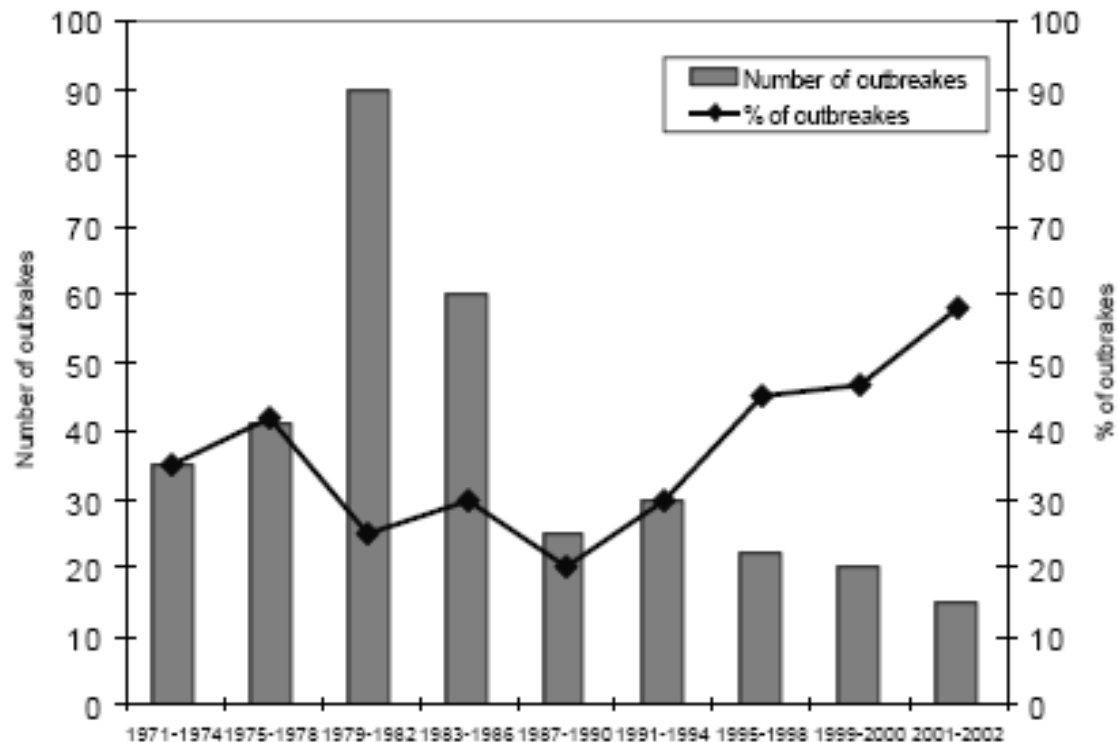


Figure 5.1. Reported waterborne disease outbreaks in the United States in community associated with distribution system deficiency (Moe and Rheingans, 2006)

DISTRIBUTION SYSTEM VULNERABILITY

- Inadequate treatment at the source?
 - Drinking water is disinfected – NOT sterilized
 - The passage of some micro-organisms is to be expected
 - It is unlikely that water quality can be improved once the water enters the distribution system
 - Water is generally consumed immediately after treatment

DISTRIBUTION SYSTEM VULNERABILITY

- A manufacturer's recall notice does not work here



DISTRIBUTION SYSTEM VULNERABILITY

- Inadequate treatment at the source?
 - “If the required continuous disinfection is not being provided, an immediate boil water advisory is recommended”
 - Microbiological sampling is generally most intense in the distribution system rather than immediately after treatment
 - Monitoring in the distribution system often provides the first indication that something has gone wrong at the plant!

DISTRIBUTION SYSTEM VULNERABILITY

- Intrusion of pathogens
 - Distribution/storage systems are not completely isolated from the environment
 - Some entry of micro-organisms is to be expected
 - Steps must be taken to prevent the entry of pathogenic organisms and/or ensure that they are inactivated prior to the consumer

DISTRIBUTION SYSTEM VULNERABILITY

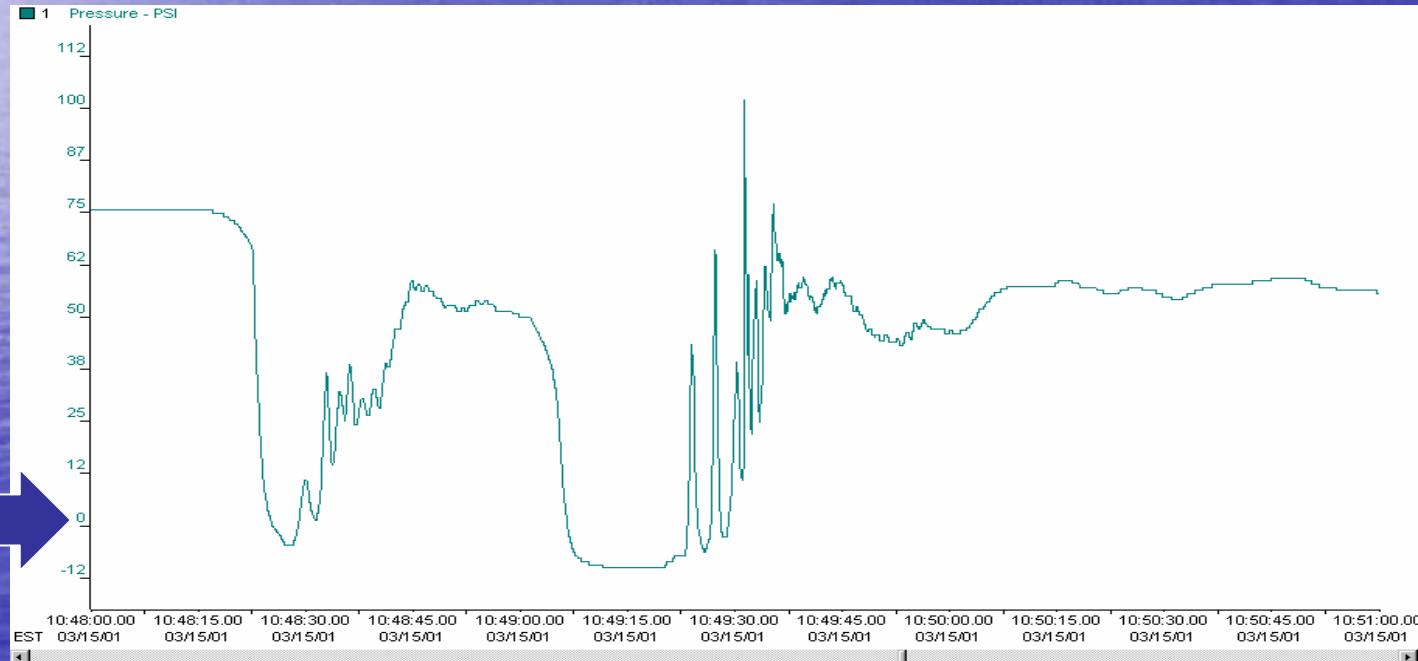
- Intrusion of pathogens can occur because of:
 - Depressurization due to watermain breaks...
 - Contamination during maintenance, installation or repairs
 - Inadequate storage facility protection
 - Cross connections/backflow

DISTRIBUTION SYSTEM VULNERABILITY

- Maintaining water pressure is the most effective tool in preventing the intrusion of pathogens into the distribution system.
 - While loss of pressure may allow the ingress of pathogens, negative pressures can actually draw them in

DISTRIBUTION SYSTEM VULNERABILITY

- Negative pressures can be a result of “normal” system operation
 - Pressure transients (surges, water hammer)



Negative pressure for greater than 16 seconds

DISTRIBUTION SYSTEM VULNERABILITY

- Another potential source of contamination?



DISTRIBUTION SYSTEM VULNERABILITY

- Intrusion of pathogens – case study
 - Cabool, Missouri - Dec., 1989 – Jan., 1990
 - *E. Coli* entered distribution system, likely during 45 water meter replacements and/or 2 large watermain breaks
 - Concurrent sewage overflow?
 - Only limited flushing
 - Super-chlorination was not practiced
 - No sampling prior to return to service
 - 243 ill, 32 hospitalized, 4 deaths

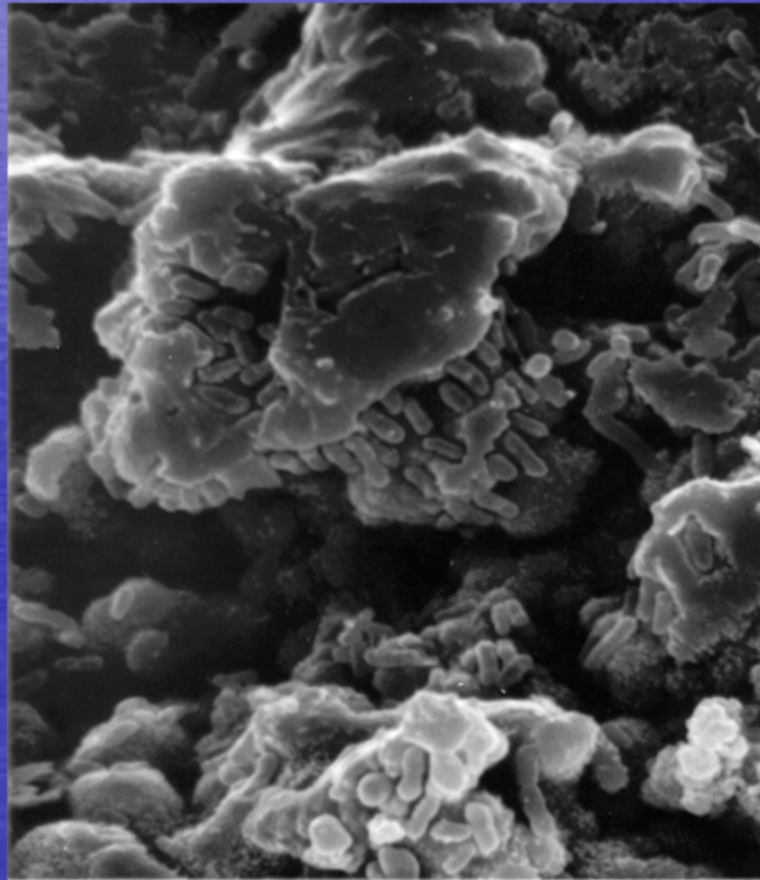
DISTRIBUTION SYSTEM VULNERABILITY

- Intrusion of pathogens – case study
 - Gideon, Missouri, 1993
 - *Salmonella typhimurium* entered distribution system, bird droppings entering tank was most plausible explanation for contamination
 - Groundwater supply thought to be secure
 - No primary or secondary disinfection
 - Lack of adequate monitoring
 - Distribution system in poor condition
 - Taste & odour problems from time to time triggered flushing
 - Drawdown of contaminated storage tank during extreme flushing increased contamination in the system
 - Late recognition of outbreak and issuance of boil water advisory
 - 650 ill, 7 deaths

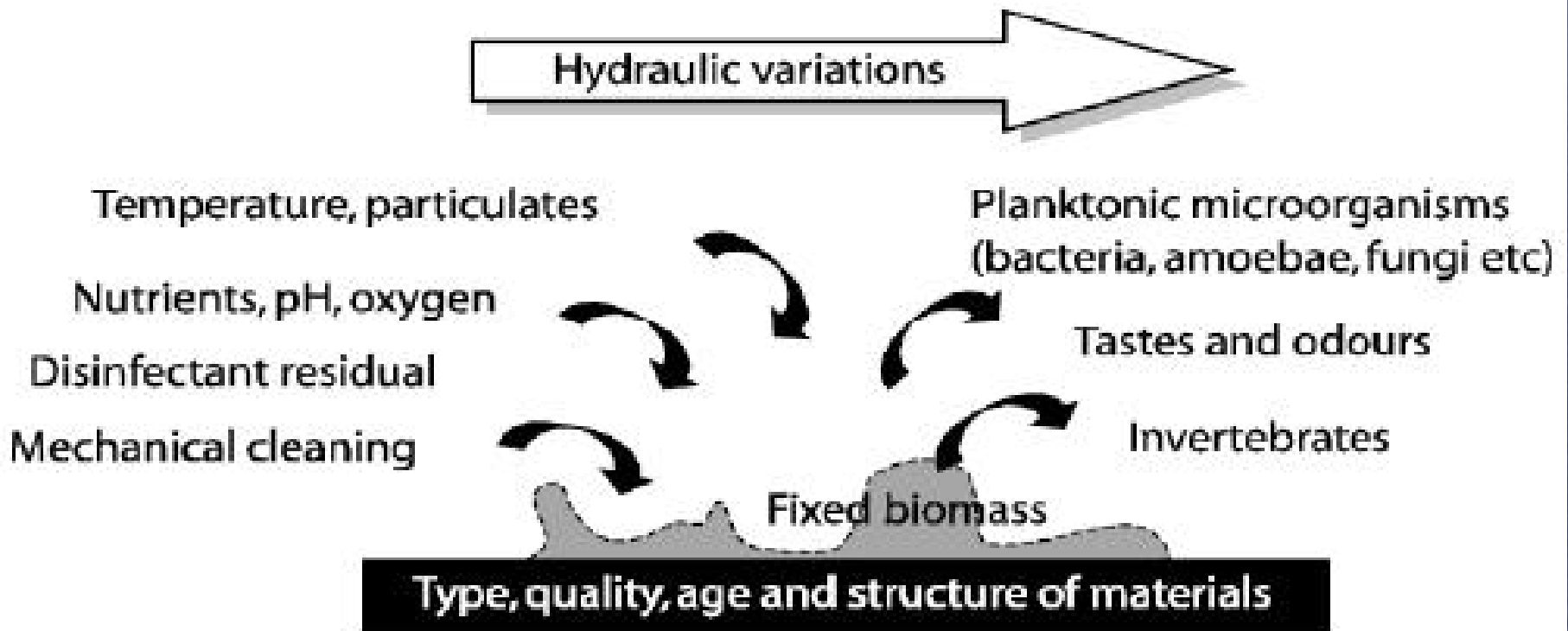
DISTRIBUTION SYSTEM VULNERABILITY

- Regrowth of bacteria within the system
 - Bacteria that enter a system may persist and multiply
 - The preferred habitat is attachment to surfaces
 - It is believed that biofilms (a dynamic microenvironment composed of bacteria in an extracellular matrix attached to a surface (Slime!)) are present in all distribution systems to some degree

DISTRIBUTION SYSTEM VULNERABILITY



DISTRIBUTION SYSTEM VULNERABILITY



DISTRIBUTION SYSTEM VULNERABILITY

- Significance of regrowth
 - Some organisms that grow in biofilms have been classed as opportunistic pathogens
 - They may be of little threat to the healthy population but can be a serious threat to susceptible people such as those that are immunocompromised
 - While organisms that actually grow within biofilms may not present a threat to healthy individuals, the biofilm environment can help any introduced pathogens persist for a longer period of time

DISTRIBUTION SYSTEM VULNERABILITY

- Significance of regrowth
 - Impact on interpreting the significance of microbiological monitoring results due to increased coliform positive samples and elevated heterotrophic plate counts (HPC)
 - Boil water advisories?
 - Can lead to generation of tastes, odours or other undesirable water quality changes
 - Potential for increased corrosion

DISTRIBUTION SYSTEM VULNERABILITY

- Nitrification
 - A microbial process by which ammonia is sequentially oxidized to nitrite and nitrate
 - Can occur in systems with a natural presence of ammonia but is more common in systems that add ammonia to convert free chlorine to chloramine
 - Decreases chloramine residual in the system
 - Increases nitrite and nitrate which can be a health risk for infants (methemoglobinemia)

The background of the slide is a photograph of a vast blue ocean under a bright blue sky with wispy white clouds. The sun is visible on the left side, creating a shimmering reflection on the water's surface.

PROTECTING THE DISTRIBUTION SYSTEM

PROTECTING THE DISTRIBUTION SYSTEM

- Appropriate treatment of the source;
 - Log removal as determined by meeting C^*t requirements represents % rather than absolute inactivation
 - Source waters impacted by high pathogen loading may require higher log removal targets
 - Although log removal may be adequate, this does not necessarily mean that the water will be biologically stable upon entering the distribution system

Effect of Chlorination on Inactivating Selected Pathogens

Organism	Cl ₂ (mg/l)	Time (min)	Ct Factor (mg-min/l)	Reduction (%)	Reference
<u><i>Campylobacter jejuni</i></u>	0.1	5	0.5	99.99	Blaser et al, 1986
<u><i>Salmonella typhi</i></u>	0.5	6	3	99	Korol et al, 1995
<u>Rotavirus</u>	0.5-1	30	22.5	100	Keswick et al, 1985
<u><i>Cryptosporidium parvum</i></u>	80	90	7200	90	Korich et al, 1990

PROTECTING THE DISTRIBUTION SYSTEM

- Preventing pathogen intrusion
 - Safe operations and maintenance practices
 - Avoid loss of pressurization and fix leaks
 - Prevent contamination during maintenance, installation or repairs
 - Disinfect and sample prior to return to service
 - Secondary disinfection
 - Maintain an adequate disinfectant residual throughout the system
 - Control cross connections and backflow

PROTECTING THE DISTRIBUTION SYSTEM

- Preventing regrowth of bacteria
 - Provide adequate disinfection at the source
 - Provide nutrient removal (enhanced coagulation, biological filtration, activated carbon adsorption) where necessary
 - Minimize water age in the system
 - Inspect, maintain and keep the system clean
 - Maintain secondary disinfectant residuals
 - Switch to a chloramine rather than free chlorine residual?

PROTECTING THE DISTRIBUTION SYSTEM

- Preventing nitrification
 - Optimize chlorine to ammonia ratio applied at the plant to minimize free ammonia residual
 - Approach but do not exceed 5:1 $\text{Cl}_2:\text{NH}_3\text{-N}$.
 - Minimize water age
 - Keep the system clean
 - Increase chloramine residual
 - Periodically switch to free chlorine?

**"SECONDARY" DISINFECTION
BENEFITS, LIMITATIONS,
AND UNINTENDED
CONSEQUENCES**

"SECONDARY" DISINFECTION BENEFITS

- Anticipated Benefits of "Secondary" disinfection
 - Overcome contamination that might be introduced into the system
 - Minimize growth of micro-organisms within the system
 - Prevent biofilm formation
 - Prevent occurrence of opportunistic pathogens
 - Stabilize water quality in the system

"SECONDARY" DISINFECTION LIMITATIONS

- Studies have shown that;
 - Chlorine residuals may be overwhelmed by chlorine demand during contamination events
 - The risk is higher for chlorine-resistant organisms such as viruses and protozoa

"SECONDARY" DISINFECTION LIMITATIONS

- While a disinfectant residual can be helpful in controlling the regrowth of coliforms and biofilm within a distribution system, total elimination of biofilm growth is unlikely
 - Pathogens may survive if introduced by intrusion and opportunistic pathogens may grow in numbers

"SECONDARY" DISINFECTION LIMITATIONS

- Critical conditions for introduced pathogen persistence (especially in biofilm) include intrusion under low or no flow, and time prior to contact with disinfectant
 - Conditions often experienced during main breaks and repairs!

AWWA Journal Oct. 2008

"SECONDARY" DISINFECTION LIMITATIONS

- Absence of residual can serve as a sign of contamination
- However, in distribution, the residual may also be reduced or lost for a number of other reasons;
 - Water age
 - Corrosion related reactions
 - Reactions with sediments and deposits within a system

"SECONDARY" DISINFECTION LIMITATIONS

- An unexpected loss of residual disinfectant is cause for concern and investigation.
- Need to have an understanding of "normal" levels throughout the system



"SECONDARY" DISINFECTION LIMITATIONS

- Investigation of loss of residual should consider;
 - Treatment problems?
 - Operational changes?
 - Water age changes?
 - Maintenance and repair work?
 - Backflow?
 - Security breeches?

UNINTENDED CONSEQUENCES OF SECONDARY DISINFECTION

- Disinfection by-products (DBPs) are compounds which are formed by unintended reactions between disinfectants and source water constituents.
- While a significant fraction of chlorination DBPs may form during primary disinfection, continued reactions with free chlorine, or in some cases chloramine, in the distribution system can lead to MAC exceedances.

UNINTENDED CONSEQUENCES OF SECONDARY DISINFECTION

- Changes in treatment at the plant may result in unintended consequences such as increased corrosion or destabilization of deposits and protective films
 - A changeover from free chlorine to chloramine as a secondary disinfectant in Washington D.C. resulted in severe destabilization of deposits in lead service lines and extremely elevated drinking water lead levels

UNINTENDED CONSEQUENCES OF SECONDARY DISINFECTION

- Consumer concerns
 - Chlorinous tastes & odours
 - Safety – drinking bleach?
 - “It is not considered necessary at this time to establish a guideline for chlorine in drinking water, based on its low toxicity at concentrations found in drinking water as a result of treatment. Any measures taken to limit the concentration of chlorine or its by-products in drinking water supplies must not compromise the effectiveness of disinfection.”
 - ❖ Health Canada, June 2009
 - NOTE: health Canada has set an MAC of 3 mg/L for chloramines

SUMMARY

- Pathogenic organisms are the greatest threat to drinking water safety
- A secure distribution system is the last barrier for protection all the way to the tap
- Efforts to control chemical risks must not result in increased microbiological risk
- A disinfectant residual can be an important protective measure but cannot replace due diligence in maintaining all of the multiple barriers which are available

THANK YOU !



QUESTIONS?