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Climate change and opportunistic pathogens (OPs) in the built environment

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NCCEH EH Seminar Series
Oct 26, 2022

“infectious diseases acquired by inhalation from environmental sources”

Outline

- Overview of selected opportunistic pathogens
- Climate change
  - Effects on growth
  - Effects on patterns of exposure
- Does how we manage risks posed by OPs change in a changing climate?

ciphi Environmental Health Review
The Journal of the Canadian Institute of Public Health Inspectors

Climate change and opportunistic pathogens (OPs) in the built environment

Juliette O'Keeffe*
Environmental Health & Knowledge Translation Scientist, National Collaborating Centre for Environmental Health, Vancouver, BC, Canada

Introduction

Climate change is predicted to have diverse impacts on the natural and built environment, including the aquatic habitats that exist in towns and cities. Within built infrastructure, the water distribution lines, premise plumbing, pools, spas, and green infrastructure can harbour a range of opportunistic pathogens (OPs), such as *Legionella*, *Mycobacteria*, and *Pseudomonas* spp., that can cause serious infections and disease outbreaks among exposed, susceptible persons. Water in ponds, ditches, or even roadside puddles can also be reservoirs where these organisms can grow and subsequently be dispersed. In Canada, the only notifiable OP-related disease is legionellosis (including Pontiac fever and Legionnaires' disease (LD)), caused by *Legionella*. Legionellosis cases in Canada have risen from an average of 0.29 per 100,000 persons before 2010 to over 1.7 in 2018 and 2019 (Government of Canada, 2021). In Ontario, just three OPs, nontuberculous mycobacterium (NTM), *Legionella* spp., and *Pseudomonas* spp., represented 83% of hospitalizations and 97% of deaths attributable to a known waterborne pathogen (Greco et al., 2020). In the United States, the estimated cost of treating diseases caused by these OPs range from around $1.5 to $2.4 billion per year, and NTM-related infections are increasing (Donohue et al., 2015; Falkinham, 2020; Proctor et al., 2022) as are cases of legionellosis in many other countries (Cassell et al., 2021; Fischer et al., 2022; Fukushima et al., 2021). This may be further exacerbated by climate change (Health Canada, 2022). Climate change may affect the survival and propagation of OPs in the built environment and affect routes of transmission and patterns of exposure in numerous ways. The key drivers of change for growth and transmission of OPs in the built environment thus need further examination. This paper reports on the findings of a rapid review of the literature on how climate change could influence the spread of OPs in urban centres.

Characteristics and epidemiology of OPs

Various terms are used to describe waterborne pathogens that colonize building water systems and cause infection among exposed susceptible persons. These are sometimes referred to as OPs, opportunistic premise plumbing pathogens, or drinking water–associated pathogens that cause infection (Falkinham et al., 2015a; Hayward et al., 2022; Proctor et al., 2022). In this paper, the term "OP" will be used to refer to these microorganisms that are naturally occurring in soils, surface waters, and groundwater but thrive in the built environment in distribution and premise plumbing systems (Schwake et al., 2021). A brief description of three primary OPs (*Legionella* spp., *Mycobacterium* spp., and *Pseudomonas* spp.) and the infections they cause is provided in Table 1. Common characteristics of OPs include a preference for warm water (e.g., 25–40 °C), some resistance to elevated temperatures (e.g., ~50–60 °C) and disinfection, and the ability to form or join biofilms within pipes and plumbing fixtures (Falkinham et al., 2015b; Hayward et al., 2022). Biofilms, which are an assemblage of microbial cells, polysaccharides, minerals, nutrients, debris, and silt, allow OPs to colonize plumbing and shelter themselves from disinfection (Donlan, 2002). OPs can also live within free-living amoeba, which lend OPs mobility while shielding them from disinfection (Atanasova et al., 2018). Some OPs can enter a viable but non-culturable state when growth conditions are sub-optimal, allowing microbes to survive harsh conditions and evade detection (Falkinham et al., 2015b; Hayward et al., 2022). OPs differ from other types of waterborne pathogens, such enteric bacteria like *E. coli*, which are removed by water treatment and typically do not re-emerge (Falkinham, 2020). In contrast, OPs can increase in concentration as water travels from its source to point of use (POU), as conditions within pipework, such as temperature, presence of biofilms, and reduced competition with enteric bacteria, can favour survival and growth.

OPs are more likely to affect people with risk factors such as older age, immunodeficiency, cancer, respiratory conditions, smoking, and diabetes (Falkinham, 2020). Socioeconomic factors including race, neighbourhood poverty, and some occupations (e.g., outside construction, cleaning, or roadside workers) are associated with elevated rates of legionellosis, and this disparity seems to be worsening (Barskey et al., 2022; Farnham et al., 2014).

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Opportunistic Pathogens (OPs)

- **Pathogenic** microorganisms
- **Naturally found** in aquatic and soil environments
- Can thrive in **engineered water systems**
  - drinking water distribution systems
  - premise plumbing, cooling towers, treated rec waters
- Can cause **opportunistic infections in susceptible individuals**

Legionella spp.

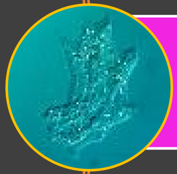
Mycobacterium spp.

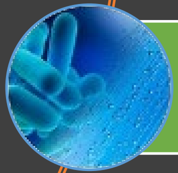
Pseudomonas spp.

Some common characteristics


Preference for **warm water**


Colonization of **engineered water systems and premise plumbing**


Some resistance to extremes and disinfection (form or join **biofilms** or FLA)


Transmission *mostly* via **inhalation of aerosols**

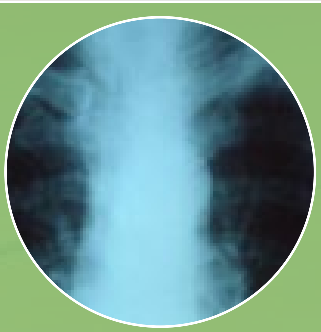

Elevated risk for **some groups**

Legionella spp.

Routes of transmission:

Inhalation

- Most **cases** are sporadic;
- Most **outbreaks** linked to cooling towers
- Hot tubs, fountains, etc. also possible sources of exposure



Outcome of infection:

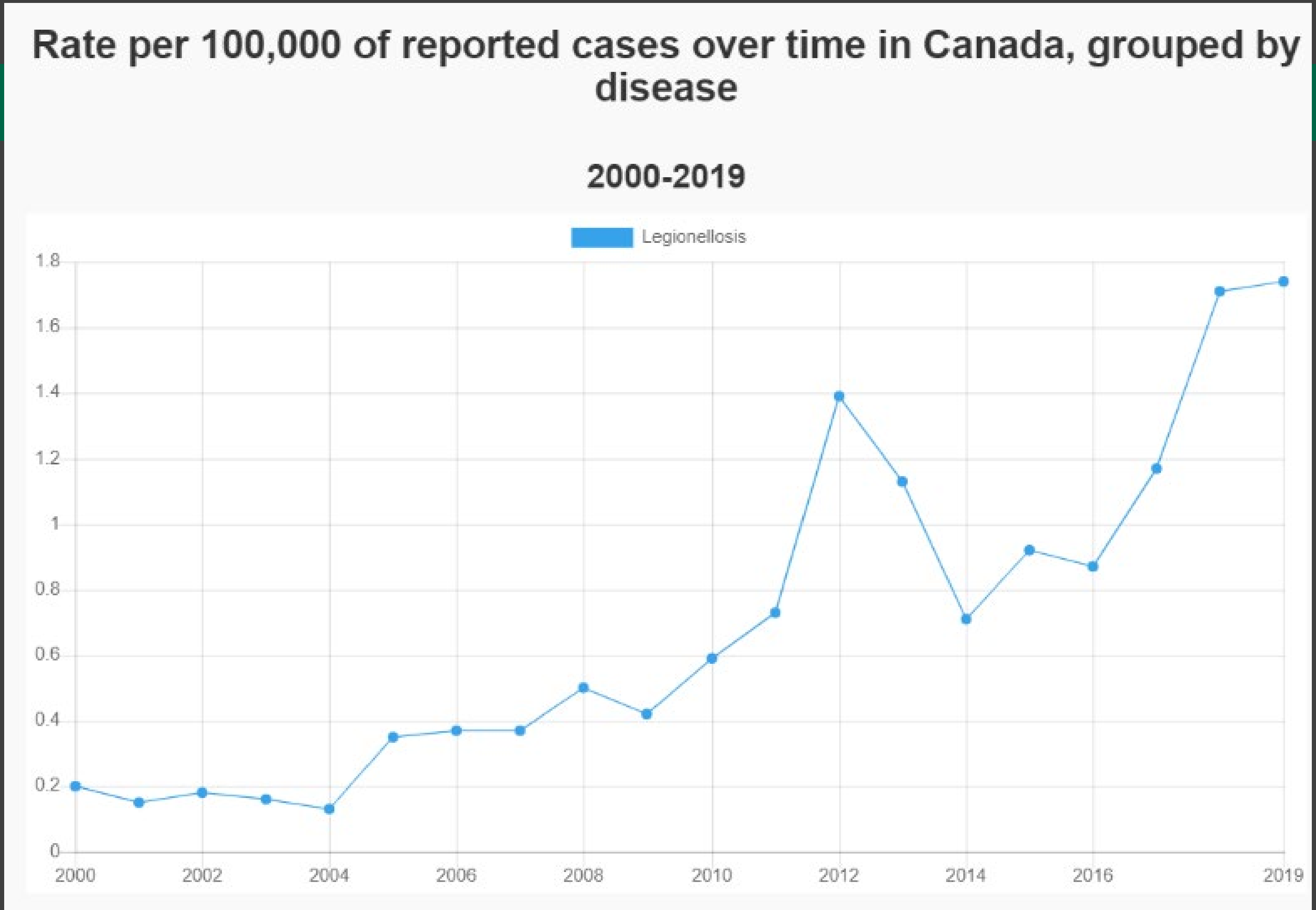
Legionellosis (reportable)

- Legionnaires' Disease (LD) (severe pneumonia, most due to *L. pneumophila*)
- Pontiac fever (milder flu-like illness)

Elevated risk:

- Smokers
- Over-50s
- Men
- Immune-compromised
- Chronic health conditions
- Outside workers, some socioeconomic groups

Legionellosis



2019: 655 reported cases in Canada
Rate: 1.74 per 100.000 persons

Source: Government of Canada. 2022. Notifiable Diseases Online. Available at https://diseases.canada.ca/notifiable [Accessed 10/14/2022]

Mycobacterium spp. specifically… Nontuberculous mycobacteria (NTM)

Routes of transmission:

Inhalation, Direct contact

- Sporadic cases - premise plumbing
- Outbreaks - recreational waters (pools/hot tubs)
- Medical/cosmetic procedures (e.g., tattooing)

Outcome of infection:

Wide spectrum of disease (non-reportable)

- Pulmonary disease (e.g., MAC)
- Soft tissue or wound infections
- Resistance to some antibiotics

Elevated risk:

- Immune-compromised
- Cystic fibrosis patients
- Elderly females

NTM – pulmonary infections

INTERNATIONAL JOURNAL OF INFECTIOUS DISEASES

INTERNATIONAL SOCIETY FOR INFECTIOUS DISEASES

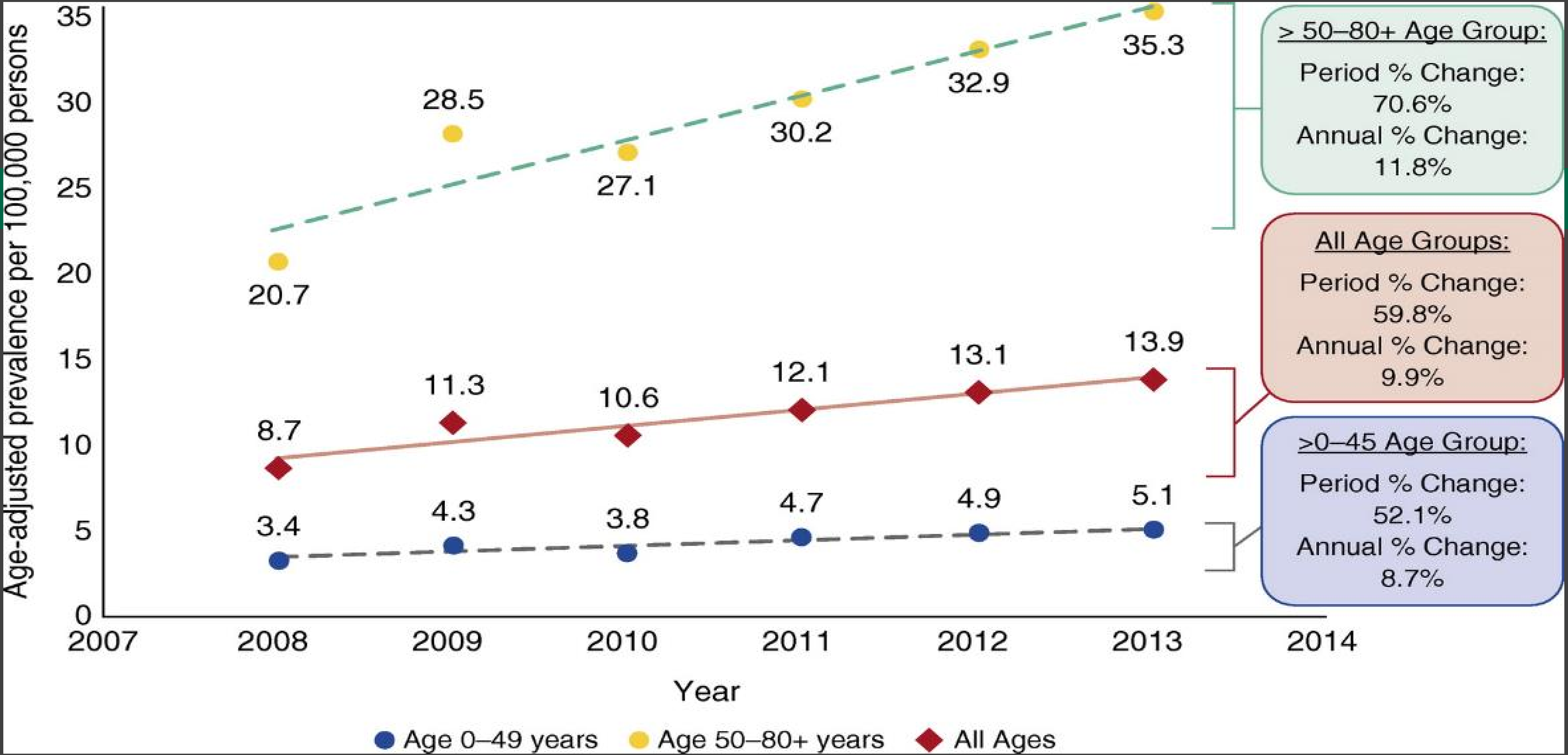
REVIEW ARTICLE | ARTICLES IN PRESS

Global trends of pulmonary infections with nontuberculous mycobacteria: a systematic review

Victor Naestholt Dahl • Martin Mølhave • Andreas Fløe • ... Prof Troels Lillebaek • Prof Aase Bengaard Andersen • Prof Christian Wejse • Show all authors

Open Access • Published: October 13, 2022 • DOI: https://doi.org/10.1016/j.ijid.2022.10.013

Most studies (81%) reporting increasing pulmonary NTM infection and disease;
Magnitude of increase ~ 4% per year.



The average age-adjusted annual prevalence of nontuberculous mycobacteria case rate per 100,000 persons. 2008 to 2013 (5 US states).

Annals ATS, 2016; https://www.atsjournals.org/doi/abs/10.1513/AnnalsATS.201605-353OC
Published in: Maura J. Donohue; Larry Wymer; *Annals ATS* 132143-2150. DOI: 10.1513/AnnalsATS.201605-353OC

Pseudomonas spp.

Routes of transmission:
Inhalation, Direct contact (ear, skin), Indirect (fomites)

- Most **dermatitis outbreaks** linked to treated recreational venues (pools/hot tubs)
- Many **pulmonary** infections are healthcare acquired (*P. aeruginosa*)

Outcome of infection:
Range of infections (non-reportable)

- Eye, skin, and ear conditions (e.g. hot tub rash, swimmer's ear,)
- Wound infections, UTIs
- Respiratory infections
- HC-acquired pneumonia

Groups most at risk:

- Cystic fibrosis patients
- Patients with wounds, invasive devices, or underlying pulmonary disease
- AMR risk - WHO Priority 1 pathogen for R&D of new antibiotics

Pseudomonas infections

- Decreasing among hospitalized patients?
  - *"Among individuals with CF, a significant decrease in the risk and rates of developing chronic P. aeruginosa infection between 2003 and 2012 was observed".* Crull et al. 2018 https://www.ncbi.nlm.nih.gov/pmc/articles/P MC6137120/

- Increases due to COVID effect?

Cell Reports

CellPress
OPEN ACCESS

Report

Acute SARS-CoV-2 infection is associated with an increased abundance of bacterial pathogens, including *Pseudomonas aeruginosa* in the nose

Nicholas S. Rhoades,[1] Amanda N. Pinski,[1] Alisha N. Monsibais,[1] Allen Jankeel,[1] Brianna M. Doratt,[1] Isaac R. Cinco,[1] Izabela Ibraim,[1] and Ilhem Messaoudi[1,2,*]
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*Correspondence: imessaou@uci.edu
https://doi.org/10.1016/j.celrep.2021.109637

- Climate effect?

ELSEVIER
International Journal of Hygiene and Environmental Health
Volume 223, Issue 1, January 2020, Pages 151-158

Thinking outside the box: Association of antimicrobial resistance with climate warming in Europe – A 30 country observational study

Hani E.J. Kaba [a], Ellen Kuhlmann [b], Simone Scheithauer [a]

"Our data highlight increases in carbapenem-resistant P. aeruginosa (CRPA) under exposure to a warming climate. In particular, the CRPA prevalence might double by 2039 in some [northwest countries], which are likely to experience stronger climate change."

Gerver et al. (2018)

England 2009-2018
Higher incidence in summer/autumn than spring/winter

https://doi.org/10.1016/j.jhin.2021.11.013

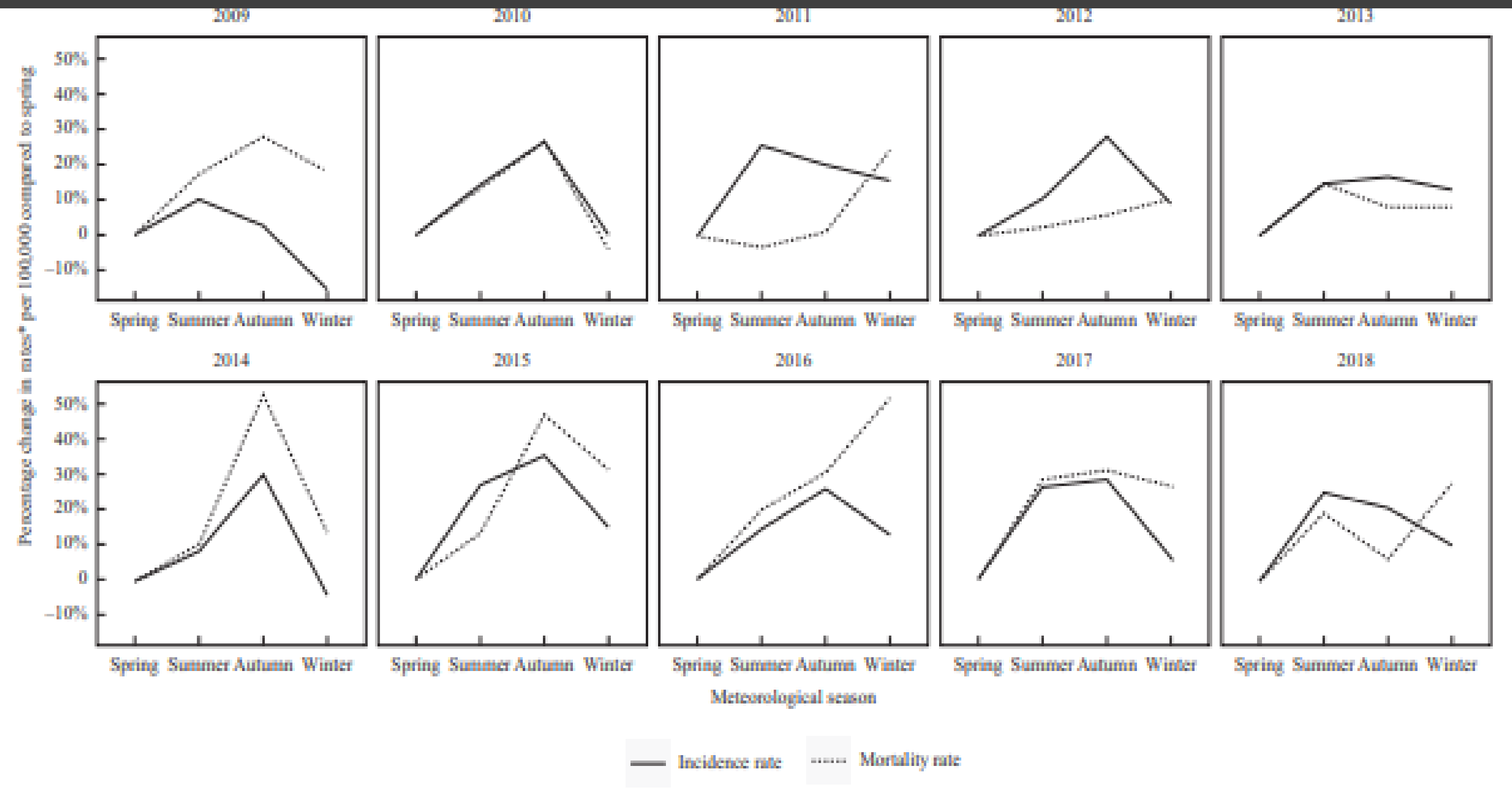
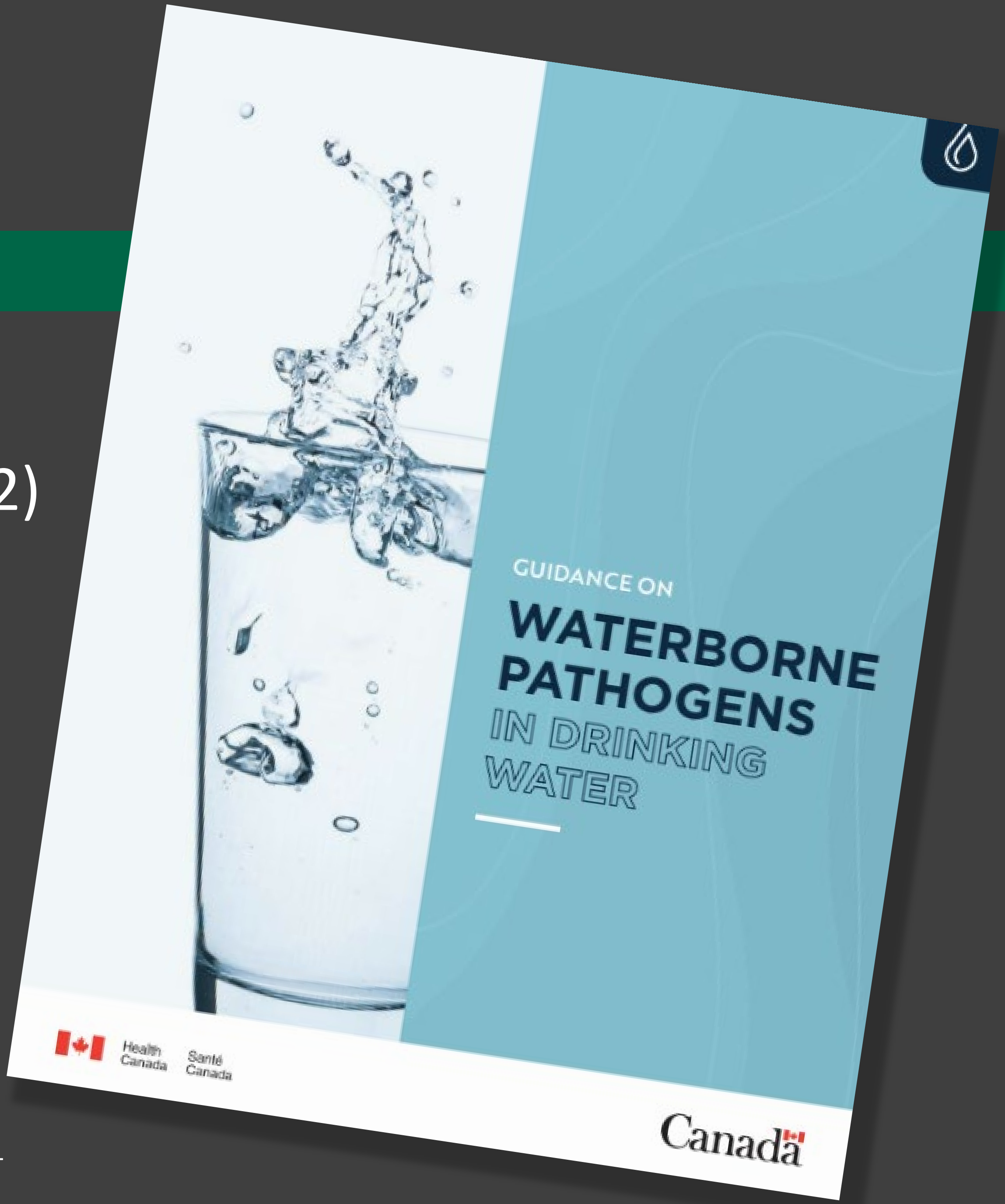


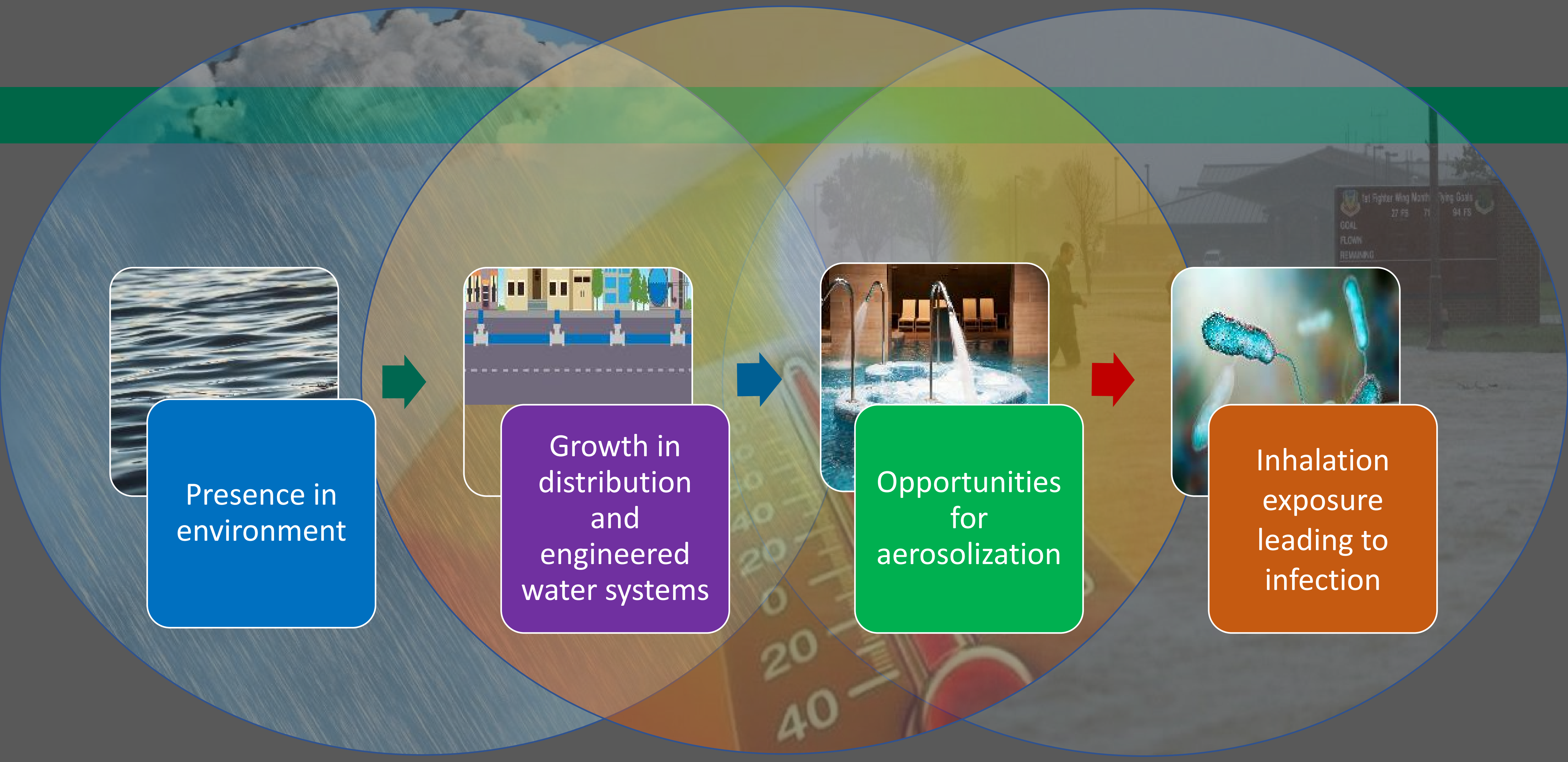
Figure 1. Seasonal pattern in incidence rates of *Pseudomonas* spp. bloodstream infections in England: 2009–2018.

New Health Canada Publication (Sept 2022)

Guidance on waterborne pathogens in drinking water

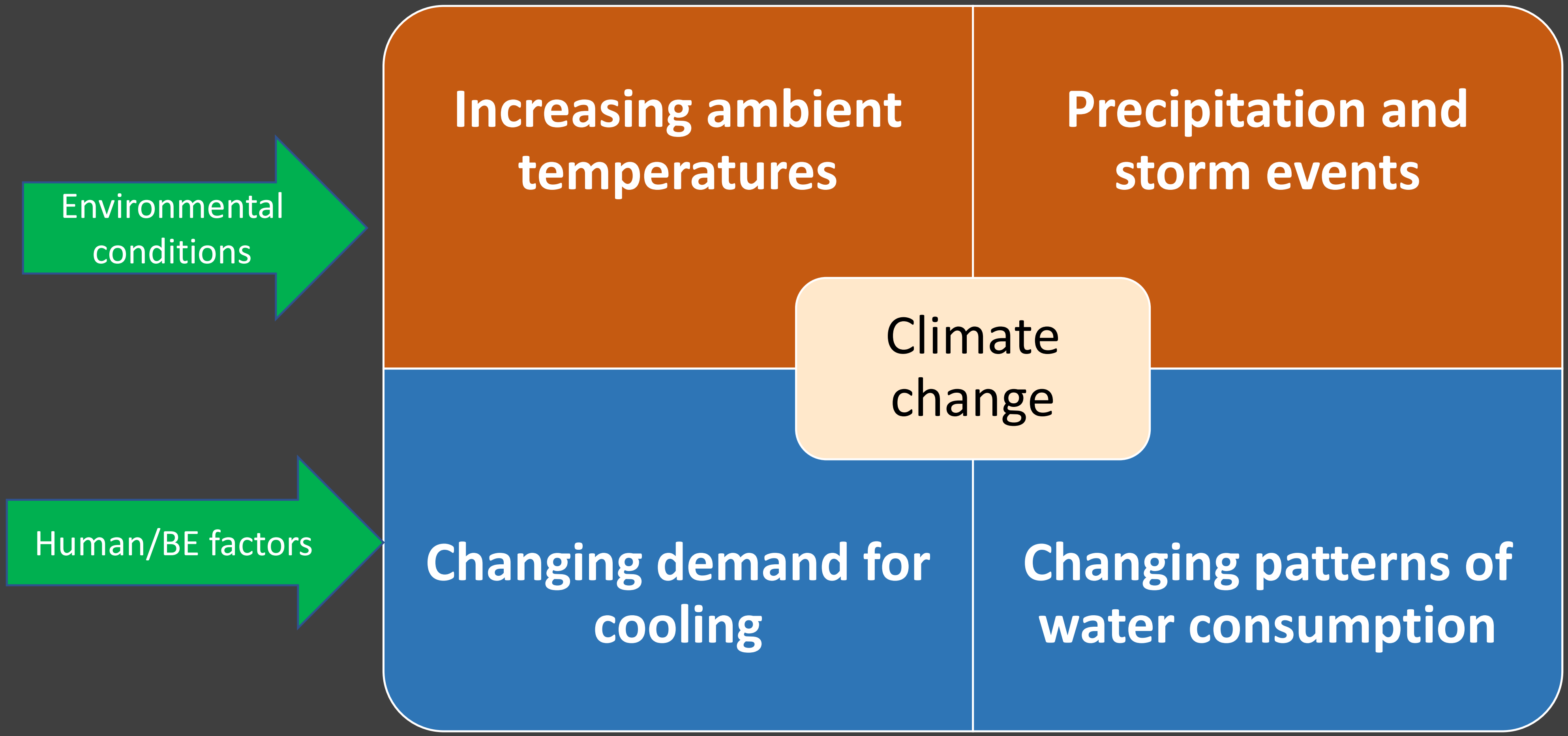


https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/water-quality/guidance-waterborne-pathogens-drinking-water.html



Images: Dows lake ottawa_Marc-Olivier Jodoin via Unsplash; Circular photos used under Creative commons licence. All others supplied by Getty Images

Understanding the climate change impacts on OP growth, survival, and human exposures



Increasing ambient temperatures

- Generally enhanced survival and propagation of OPs with warming

(Fisman et al., 2005; Brandsema et al., 2014; Beauté et al., 2016; Simmering et al., 2017 ; Walker, 2018 ; Han, 2019; Passer et al., 2020; Blanc et al., 2021)

- Changing seasonal patterns (e.g., legionellosis cases may start earlier and last longer)
    - E.g., Alarcon Falconi et al. 2018 - notable shift of seasonal peaks from mid-September pre-2003 to mid-August post-2003 (US)

(Alarcon Falconi et al., 2018; Park et al., 2019; Fukushima et al., 2021; Fischer et al., 2022)

- Hot and humid climates more favourable for *Legionella*, NTM transmission, than hot and dry (decline in these areas?)

(Fisman et al., 2005; Beauté et al., 2016; Gleason et al., 2016; Simmering et al., 2017 ; Prussin et al., 2017 ; Han, 2019; Villanueva & Schepanski, 2019 ; Passer et al., 2020; Blanc et al., 2021; Barskey et al., 2022)

Increasing ambient temperatures

- Key concerns
  - Enhanced **growth** in the environment
  - Increasingly difficult to maintain LOW temperature to prevent growth (e.g., < 20°C)
    - In **distribution system**

      (Walker, 2018; Agudelo-Vera et al., 2020Blanc et al., 2021; Calero Preciado et al., 2021)

    - In **premise plumbing** especially in urban centres

      (Lu et al., 2017; Dai et al., 2018)
  - Increased decay of disinfectant residuals

Precipitation and storm events

- ## Heavy precipitation

  > Rainfall shows a strong association with legionellosis – time lag of several days; (NTM?)

  > Contamination of source waters with storm flow > harder to treat > **enhanced conditions for growth;**

  > Possible **increased generation of aerosols**

  (Fisman et al., 2005; Hicks et al., 2007; Garcia-Vidal et al., 2013; Gleason et al., 2016; Beauté et al., 2016; Braeye et al., 2020; Passer et al., 2020; Blanc et al. 2021; Mitsui et al., 2021; Zhang and Lu 2021; Mapili et al. 2022)

- ## Storm events and wind

  > Windblown debris > **contaminate cooling towers** > depletes disinfectant residuals > growth of OPs. (e.g., hurricane affected states)

  > **Dispersal of bioaerosols** from more distant sources (e.g., wastewater treatment plants)

  > **Flood waters and mud** can be sources of exposure

  (Walker 2018; Oda et al. 2019; Brigmon et al. 2020; ECDC 2021; Mitsui et al. 2021)

Precipitation and storm events

- Key concerns
  - Increased contamination of source waters
    - Enhanced growth in the environment
    - Increased treatment challenges
  - Increased aerosolization of ambient NTM or *Legionella*. Some people more at risk:
    - Outside workers, drivers, and pedestrians may be more exposed
    - Persons involved in flood cleanup

Changing climate > changing demand for cooling

- Cooling towers are prone to colonization by *Legionella* and a primary source of legionellosis outbreaks
  - Key concerns
    - An increase in favourable conditions for colonization and dispersal of aerosols from cooling towers
    - Additional cooling demand could increase the number and duration/frequency of use of cooling systems

Changing demand for cooling

- New or increased sources of aerosol or contact exposure for cooling
  - Water misters
  - Splash parks and pools

- New or increased sources of aerosol exposure for green infrastructure (e.g., living walls)

  - e.g., Aerosolization of irrigation water

pathogens

MDPI

Article

Opportunistic Premise Plumbing Pathogens. A Potential Health Risk in Water Mist Systems Used as a Cooling Intervention

Edmore Masaka *, Sue Reed, Maggie Davidson and Jacques Oosthuizen

- Biofilm, bioaerosol, and water samples from WMS in NW Australia
  - 71% positive for OPs
    - *P. aeruginosa* in 44% (*more frequent in bioaerosols than water and biofilm*)
    - *L. pneumophila* (Sg 2-14 and Sg 1) in 24% (*more frequent in water than biofilm*)
    - *M. avium* no positive samples

Masaka et al. 2021. Available at: https://doi.org/10.3390/pathogens10040462

Changing patterns of water consumption

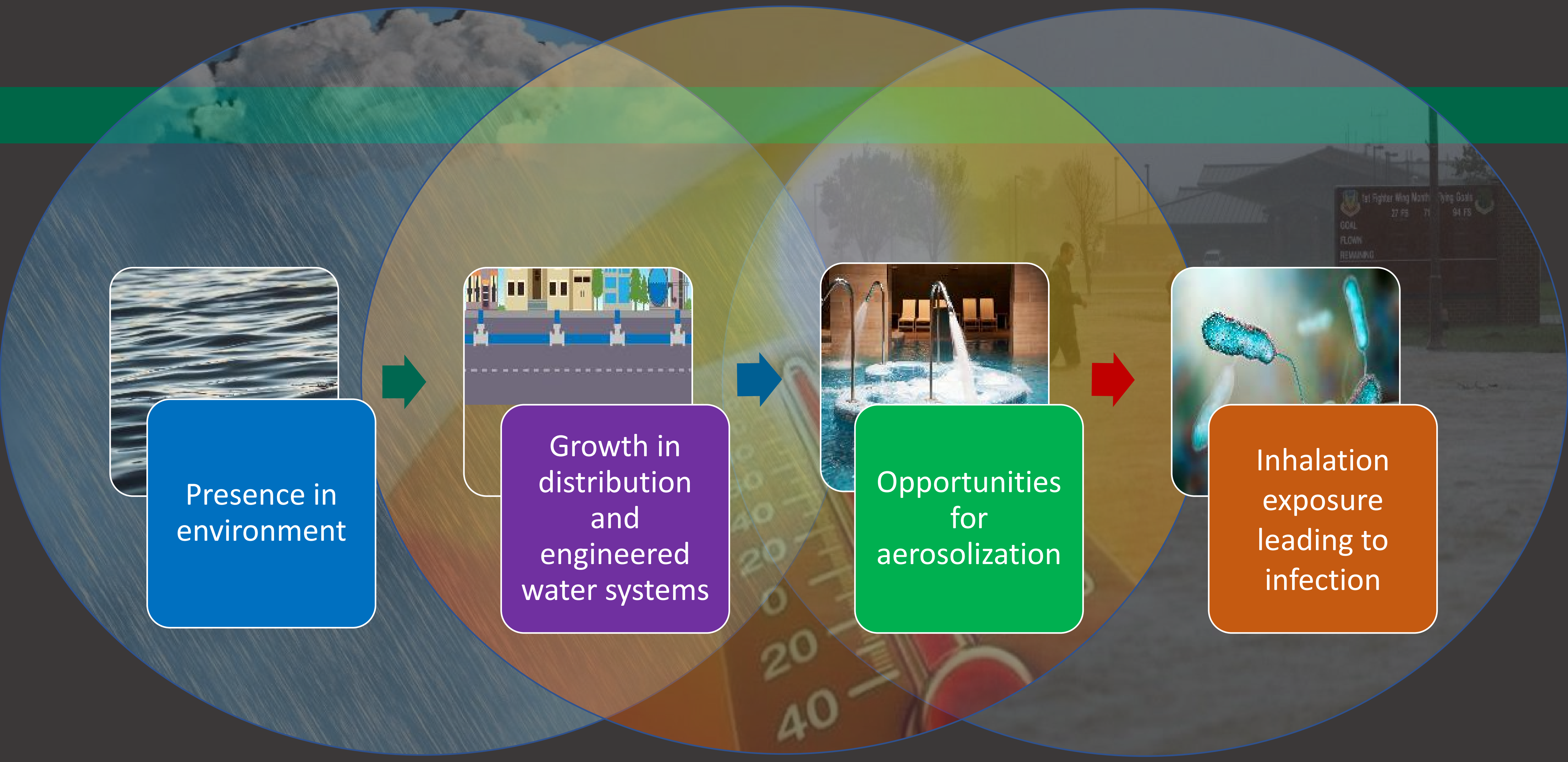
In Ontario, municipal drinking water treatment and pumping accounts for around a fifth of municipal energy use (*Environmental Commissioner of Ontario, 2017*)

- Addressing climate change includes reducing water consumption and waste
  - Water efficient devices
  - Automatic or low flow devices
  - Water reuse
    - Grey water or Rainwater harvesting

… how does this affect OP growth or exposures?

Changing patterns of water consumption

- Periods of low use or water efficiency measures can result in an increase in **water age**
  - Reduced disinfectant residual, enhanced growth conditions
- Electronic faucets may facilitate **colonization of plumbing fittings** (e.g., *P. aeruginosa*)
  - Low flow, limited temperature control
- Harvested rainwater or greywater
  - Collection surfaces (e.g., debris, ash)
  - Uses that **generate aerosols** (cooling towers, irrigation, toilet flushing, or fire suppression) can introduce new **sources of exposure**



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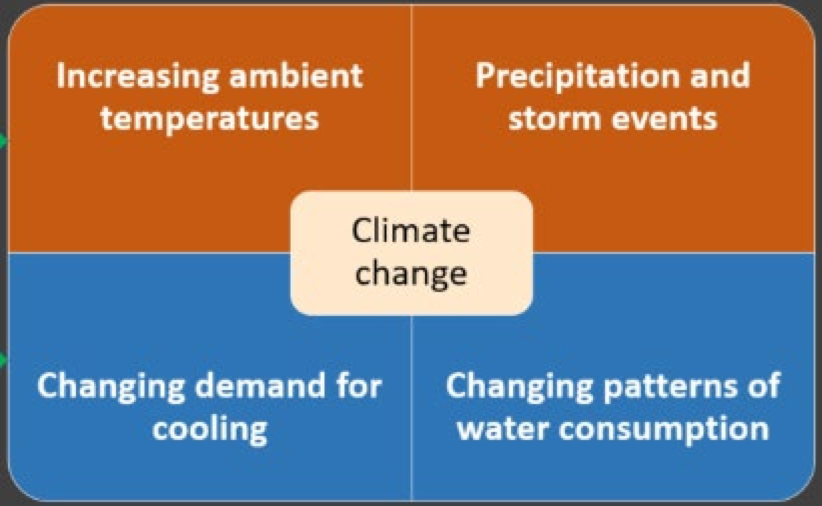
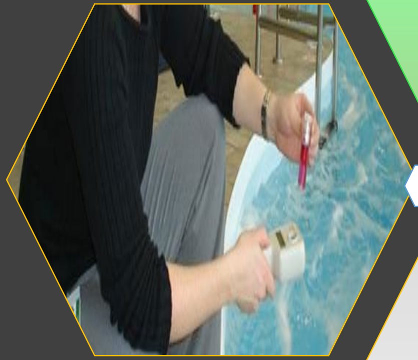
… overall…



- Possible increased **contamination of source water, cooling towers or other** raw water sources, enhancing growth and making treatment more difficult
- Increasing **colonization of engineered water systems** due to temperature or changing patterns of use, making it harder to maintain OP free systems
- Increased **exposure to aerosolized water** in the built environment
  - Outside during storms/precipitation/wind
  - More cooling towers or increased use
  - New or increasing exposure to other sources of aerosolized water

Existing controls

Limit nutrients (TOC, N, P, Fe)

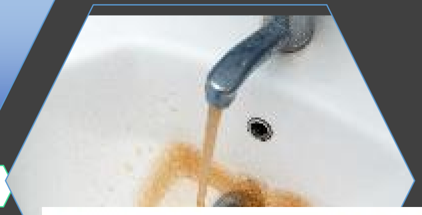


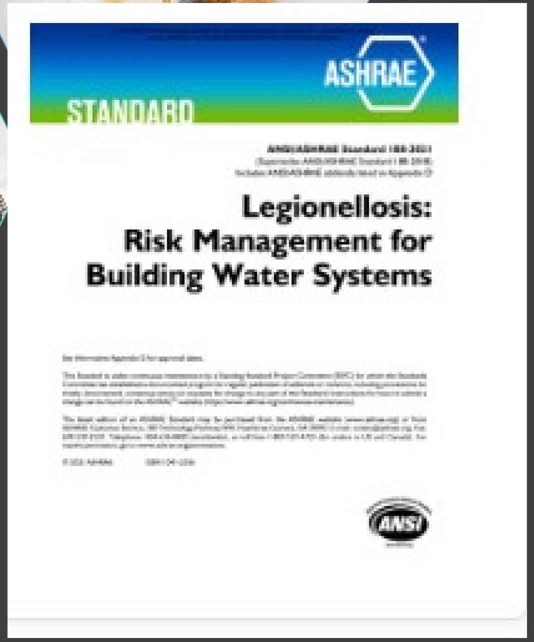
Disinfection

Temperature controls

Plumbing materials

Hydraulic Controls (e.g., flushing)





Managing risk posed by OPs in a changing climate

Upstream measures – Source water protection

- Adapting treatment for a changing climate
  - Seasonal changes
  - Floods
  - Precipitation following wildfires
- Protecting source water to maintain treatability
  - Low turbidity
  - Low TOC
  - Primary disinfection
    - Secondary residuals

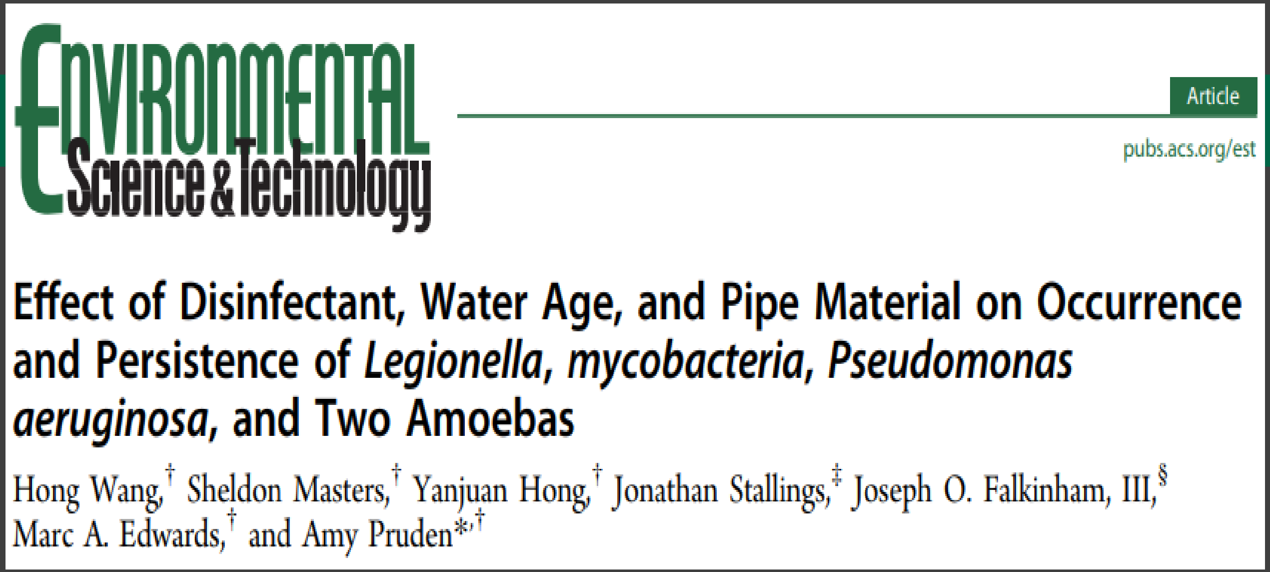
Image credit top right: Capilano reservoir photo credit SqueakyMarmot @www.flickr.comphotos37804160@N0035886245470

Managing risk posed by OPs in a changing climate

Upstream measures – Maintaining high quality water within distribution networks

- Awareness of how CC will affect **in-pipe factors** that enhance growth or reduce disinfectant residual
    - corrosion, biofilms, available nutrients, TOC
- Balancing **adequate disinfection** with risks of **disinfection by-products** (toxic or carcinogenic compounds)
- Changing hydraulic conditions? Intermittent periods of low use? Drought?

Cullom et al. 2020. Critical review: propensity of premise plumbing pipe materials to enhance or diminish growth of *Legionella* and other opportunistic pathogens. *Pathogens*: 9(957). Available from: https://doi.org/10.3390/pathogens9110957



Environmental Science & Technology

Article

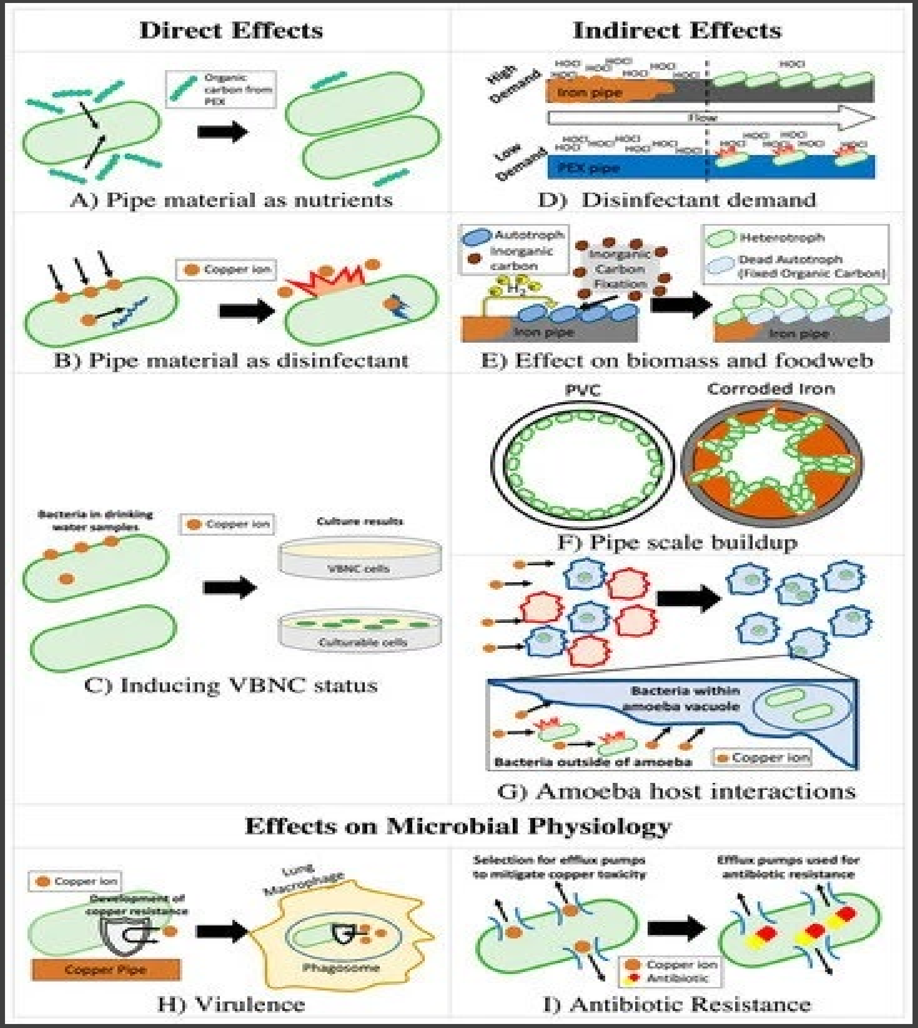
pubs.acs.org/est

Effect of Disinfectant, Water Age, and Pipe Material on Occurrence and Persistence of *Legionella*, *mycobacteria*, *Pseudomonas aeruginosa*, and Two Amoebas

Hong Wang,[†] Sheldon Masters,[†] Yanjuan Hong,[†] Jonathan Stallings,[‡] Joseph O. Falkinham, III,[§] Marc A. Edwards,[†] and Amy Pruden*[,†]

- Disinfectant type and dose had strongest influence on microbiota.
- Pipe material became more important as water aged and disinfectant residual reduced.

Overview of exemplar mechanisms by which pipe materials can affect OPs in premise plumbing



Impact of climate factors on (e.g., extreme heat) on in-pipe factors?

Managing risk posed by OPs in a changing climate

Downstream measures: point of entry or point of use:

Additional controls?

- POE/POU **treatments?**
  - Disinfectant addition (chlorine or other); UV disinfection;
  - Membrane filtration (<0.22 µm)
- Increased system flushing?
  - **Flushing** stagnant water, hydraulic action, replenishing residual
  - **Heat shock** (e.g., 70°C for 30 minutes)
- Design controls to **reduce water age**
  - Sizing pipes and storage systems to demand)

Managing risk posed by OPs in a changing climate

Downstream measures

- Water management plans – are control measures still adequate?
  - Identify areas of changing risk to adapt risk-reducing measures
  - May need to revise more frequently in the context climate change
    - e.g., Seasonal adaptations? Impact of storms, precipitation?
- Are operation and maintenance procedures are still adequate?
  - Can temperature management (e.g., < 20°C) be maintained?
  - Inspection, monitoring, maintenance may become more important
    - POU fixtures, fittings, equipment (faucets, showerheads)
- Cooling tower (and other water feature) registries
  - Inform good water management practices
  - Facilitate outbreak investigations

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Legionella

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Jun 8, 2022 Print

Jump to

Select a section

Legionella is naturally occurring waterborne bacteria that can survive within building water systems and multiply under ideal conditions that include warm temperature (e.g., 25-45°C), lack of disinfection, and the presence of biofilms. *Legionella* bacteria are also called **opportunistic premise plumbing pathogens (OPPP)** and can be

Managing risk posed by OPs in a changing climate

Additional considerations

- Some socioeconomic groups at higher risk of exposure (e.g., outside workers), **and/or** illness (e.g., socioeconomic groups with health inequities), neighbourhood factors

CDC Centers for Disease Control and Prevention

Volume 28, Number 3—March 2022

CME ACTIVITY - *Synopsis*

Rising Incidence of Legionnaires' Disease and Associated Epidemiologic Patterns, United States, 1992–2018

Albert E. Barskey✉ , Gordana Derado, and Chris Edens
Author affiliation: Centers for Disease Control and Prevention, Atlanta, Georgia, USA

On This Pa

CME Introd

" Rising incidence was most notably associated with increasing racial disparities, geographic focus, and seasonality ".

Managing risk posed by OPs in a changing climate

Where to start?

- Most at-risk buildings/neighbourhoods/regions
  - Reduced source water quality?
  - Neighbourhood factors, quality of premise plumbing?
  - Impact of warming on premise plumbing?
  - Absent WMPs?
  - Located in areas with hot/humid summers?

- Most at-risk persons
  - **Susceptible** persons (e.g., elderly, immune compromised)
  - Socioeconomic groups
  - More **exposed** (e.g., some outside occupations)
  - Impact of warming on occupiers
    - e.g., Residents more likely to seek alternative cooling?

Risk reducing measures

Challenges

- Trade-offs in balancing water treatment objectives with:
  - public safety concerns (e.g., scalding, DBPs, addressing cooling demands)
  - sustainability (e.g., water and energy conservation)

- Determining who is responsible for taking action
  - Source water protection
  - Adapting water treatment systems
  - Managing quality in the water distribution system
  - Premise plumbing
    - WMP
    - Landlord requirements (e.g., UK)
  - Environmental exposures
    - Oversight of cooling tower registries

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thank you!

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Questions?

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