# Assessment of Relative Potential for Biological Threat Agent Exposure during Uses of Drinking Water

Deliberate or accidental contamination of drinking water supplies could pose a major public health risk for water customers. Models based on HSRP's water security modeling and simulation research indicate that pathogens (disease-causing microbes) injected directly into the drinking water system could result in significant exposures to end-use water customers, especially from ingestion.

Although potential exposure risks from ingestion of contaminated water are well known, knowledge gaps for non-ingestion hazards from inhalation or skin contact are still being addressed.

U.S. EPA's Homeland Security Research Program (HSRP) develops products based on scientific research and technology evaluations. Our products and expertise are widely used in preventing, preparing for, and recovering from public health and environmental emergencies that arise from terrorist attacks. Our research and products address biological, radiological, or chemical contaminants that could affect indoor areas, outdoor areas, or water infrastructure. HSRP provides these products, technical assistance, and expertise to support EPA's roles and responsibilities under the National Response Framework, statutory requirements, and Homeland Security Presidential Directives.

A screening level microbial exposure assessment was conducted to assist HSRP and other stakeholders in better understanding potential exposures associated with pathogen contamination of drinking water supplies (Hines et al., 2014). The results of the preliminary assessment could be used to support the development of response strategies to protect human health and the environment in the event of a contamination event.

The goals of the research included:

- Understanding potential drinking water exposure pathways during common water uses

- Estimating exposure doses from ingestion and inhalation

- Developing a method for prioritizing exposure pathways that require additional or future assessment

From a comprehensive list of possible exposure sources, a set of quantifiable pathways was identified for assessment. The exposure pathways included but were not limited to:

- Ingestion from drinking water or from incidental ingestion while bathing, showering or swimming

- Inhalation from exposure to devices including humidifiers, heating and air conditioning systems, toilets, faucets, or hoses

- Inhalation from activities such showering, swimming, or watering lawns

# LEGIONELLA SPECIES

To exemplify the process utilized for the overall microbial exposure assessment, the methods, model, and results for the *Legionella* species assessment are provided below. The *Legionella* species are important waterborne pathogens in terms of disease morbidity and mortality. Legionellosis, also known as Legionnaires' disease or Pontiac fever, is a waterborne disease transmitted by inhalation of respirable water particles or aspiration of water contaminated with *Legionella* species. The most common potential reservoirs identified for transmission of legionellosis include heat-rejection equipment (e.g., cooling towers, evaporative condensers), plumbing systems (e.g., showers, faucets, hot water tanks), nebulizers, humidifiers, whirlpool spas, and public fountains.

This exposure assessment developed emission factors to model aerosolization, quantitatively assess inhalation exposures of aerosolized *Legionella* species or *Legionella* species surrogates, and rank six common in-home uses of water for potential *Legionella* species inhalation exposure.

A targeted literature search was conducted to inform development of the conceptual model (Figure 1), including identification of exposure pathways and input values for the exposure assessment. Exposure pathways from in-home use of potable water that could be associated with reported transmission of legionellosis or aerosolization of similar waterborne bacterial pathogens were identified and evaluated. If *Legionella* species data were unavailable from the published literature and respirable aerosol generation was documented, data for bacterial surrogates were also considered. Exposure sources that could be considered common sources for large numbers of individuals (e.g., cooling towers) were not evaluated in this exposure assessment.
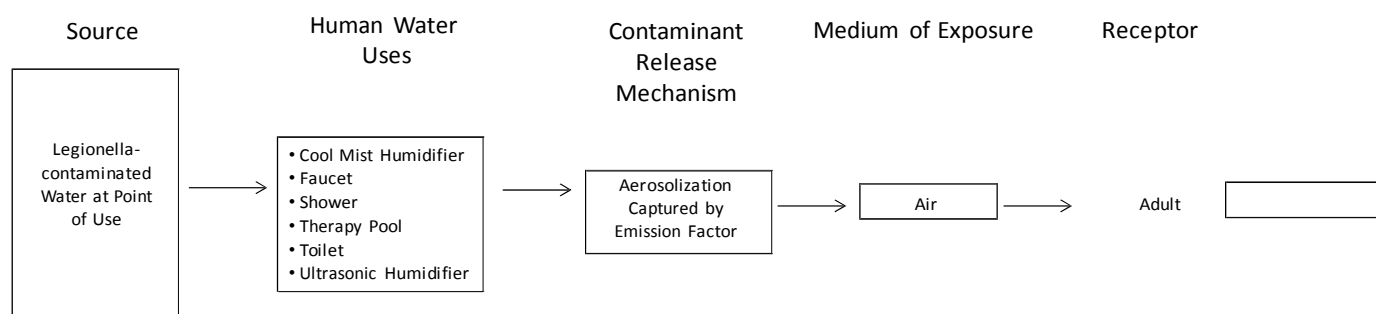


**Figure 1. Conceptual model for inhalation of *Legionella* species from identified uses of contaminated water.**

Exposure doses were calculated using Equation 1. Events were not assessed cumulatively and assumed to occur one time per day only (e.g., shower) or data were aggregated for multiple events (e.g., toilet, faucet), if available.

$$D = [EF \times C_{water}] \times IR \times ET \times CF$$

where:

D = Exposure Dose (Colony Forming Unit (CFU) or Direct Count)

EF = Emission Factor ($L/m^3$)

$C_{Water}$ = Water Concentration (CFU or Direct Count/L)

IR = Inhalation Rate ($m^3$/minute)

ET = Exposure Time (minutes or hours)

CF = Conversion Factor (Factor of 60 minutes/hour to convert ET to minutes when necessary)

Air and water concentration data identified from the literature search were used in the development of emission factor values using Equation 2.

$$EF = C_{air} / C_{water}$$

where:

EF = Emission Factor (L/m3)

$C_{Air}$ = Air Concentration (CFU or Direct Count/m3)

$C_{Water}$ = Water Concentration (CFU or Direct Count/L)

The starting water concentrations were informed by the results of the literature search and assumed the *Legionella* species concentration as measured at the point of use (e.g., at faucet, showerhead). A low end starting water concentration value of $10^3$ CFU/L was chosen based on the reported level of *Legionella* species associated with human legionellosis identified in retirement home nurses (Hautemaniere et al., 2011). The high end value of $10^5$ CFU/L was identified from the high value reported using culture-based measurements from monitoring of hot and cold water outlets in six European countries (Lee et al., 2011).

Exposure assumptions for inhalation rate and exposure time were determined for an adult mostly from the U.S. Environmental Protection Agency's Exposure Factors Handbook (EFH) (EPA, 2011) for each exposure pathway identified in the conceptual model shown in Figure 1. Peer reviewed literature was consulted if values were not available in the EFH. If data were not available in the peer reviewed literature or were of questionable quality, then best professional judgment was used to select exposure assumptions.

Considerable variability in the calculated exposure dose was identified between the six identified exposure pathways, with the doses differing by over five orders of magnitude in each of the evaluated exposure scenarios (Table 1). The assessment of exposure pathways that have been epidemiologically associated with legionellosis transmission (ultrasonic and cool mist humidifiers) produced higher estimated inhalation exposure doses than pathways where epidemiological

evidence of transmission has been less strong (faucet and shower) or absent (toilets and therapy pool).  With consideration of the limited precision of the assessment process, a relative ranking of exposure pathways from highest to lowest exposure doses was produced using culture-based measurement data.  In this ranking, the ultrasonic and cool mist humidifier exposure pathways were estimated to produce the highest exposure doses, followed by the shower and faucet exposure pathways, and then the toilet and therapy pool exposure pathways (Table 1).

**Table 1. Daily calculated dose and by exposure pathway sorted from highest to lowest values for an adult exposed to Legionella species or surrogates of Legionella species.**

| Pathway | Inhalation Rate for Central Tendency Exposure | | Inhalation Rate for Reasonable Maximum Exposure | |
|---|---|---|---|---|
| | Low Water Concentration ($10^3$ CFU/L) | High Water Concentration ($10^5$ CFU/L) | Low Water Concentration ($10^3$ CFU/L) | High Water Concentration ($10^5$ CFU/L) |
| **Daily Calculated Dose for Culture-based Measures (CFU/Day)** | | | | |
| Ultrasonic Humidifier | 8.1E+0 | 8.1E+2 | 3.2E+1 | 3.2E+3 |
| Cool Mist Humidifier | 5.5E+0 | 5.5E+2 | 2.2E+1 | 2.2E+3 |
| Shower | 8.8E-2 | 8.8E+0 | 2.6E-1 | 2.6E+1 |
| Faucet | 5.9E-2 | 5.9E+0 | 1.3E-1 | 1.3E+1 |
| Toilet | 1.7E-4 | 1.7E-2 | 3.4E-4 | 3.4E-2 |
| Therapy Pool | 1.3E-5 | 1.3E-3 | 1.6E-4 | 1.6E-2 |
| **Daily Calculated Dose for Direct Count (# Microorganisms/Day)** | | | | |
| Shower | 5.7E-1 | 5.7E+1 | 1.7E+0 | 1.7E+2 |
| Therapy Pool | 6.4E-3 | 6.4E-1 | 8.0E-2 | 8.0E+0 |

CFU – colony forming unit, EF – Emission Factor
Source: Hines et al. 2014

## OVERALL EXPOSURE ASSESSMENT FINDINGS

Although, the overall screening-level exposure assessment exampled with *Legionella* species data above was associated with high levels of statistical uncertainty, some general conclusions could be made.

1. Adult and child exposures with potential human health consequences can occur when a drinking water system is contaminated with pathogens at concentrations similar or greater to those evaluated in this exposure assessment.

2. Exposure can result from ingestion of water or from inhalation of aerosolized pathogens from common water uses.

3. Exposure pathways that included the ingestion route of exposure consistently resulted in the highest calculated exposure doses.

Identifying and addressing the major knowledge gaps remains an area of ongoing research including:

- Refinement of exposure assessment methodologies, including exposure through skin and eye contact

- Understanding factors that affect the aerosolization of biological agents (e.g., room size, water pressure, air and water temperature)

- Understanding how aerosolization changes the viability of microbes and how that affects the methods used to measure the number of microbes (e.g., if microbes enter a viable-but-nonculturable state, how can the microbial exposure dose best be measured?)

- Understanding how long microbes remain viable in contaminated drinking water and in the specific devices that might produce contaminated aerosols (e.g., shower heads, faucets, toilets, humidifiers).

## CONTACT INFORMATION

For more information, visit the EPA Web site (www.epa.gov/nhsrc).

If you have difficulty accessing this PDF document, please contact Kathy Nickel (Nickel.Kathy@epa.gov) or Amelia McCall (McCall.Amelia@epa.gov) for assistance.

**Technical contact:**    SarahTaft (taft.sarah@epa.gov)

**General Feedback/Questions:** KathyNickel (nickel.kathy@epa.gov)

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