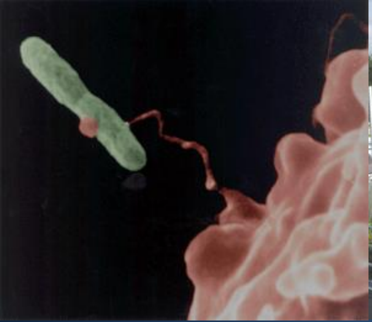


Evaluating the health risks from exposure to *Legionella* in reclaimed water aerosols

11th IWA International Conference on Water Reclamation and Reuse
7/26/17

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WRF-12-05 Development of a risk management strategy for *Legionella* in recycled water systems

WATER ENVIRONMENT & REUSE FOUNDATION

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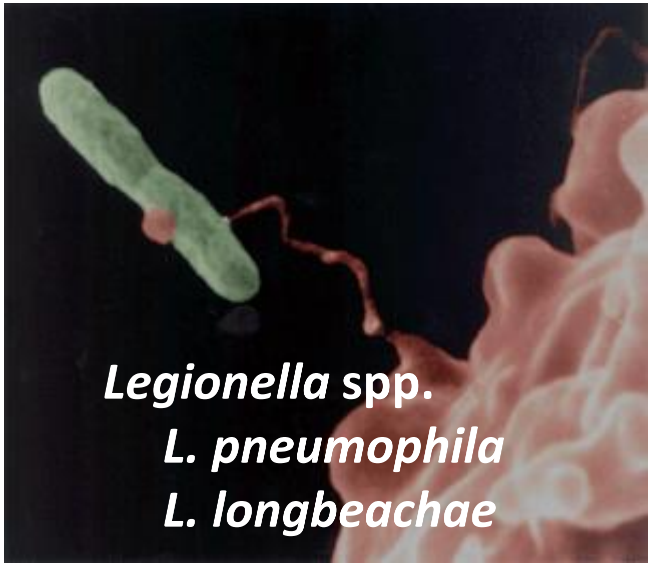
Reclaimed water

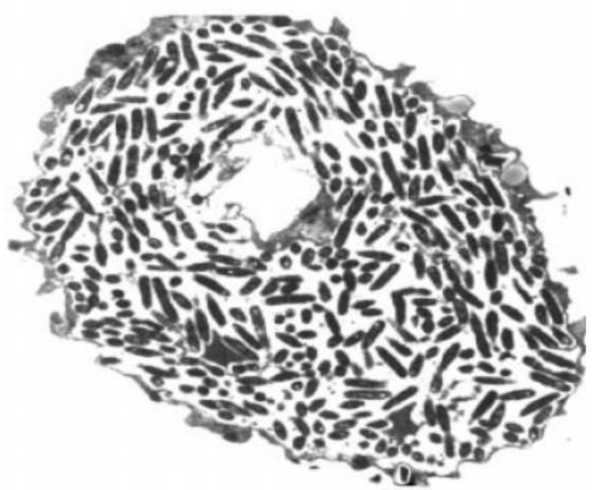
- Wastewater reused for beneficial purpose with treatment
- Level of treatment depends on **the application**

USEPA, 2012

Legionella in engineered water systems

- Most of focus on GI pathogens, what about opportunistic pathogens?
  - Inhalation exposure





***Acanthamoeba* spp.**

CDC, Kenyon College, Harb et al., 2000, Potera 2012

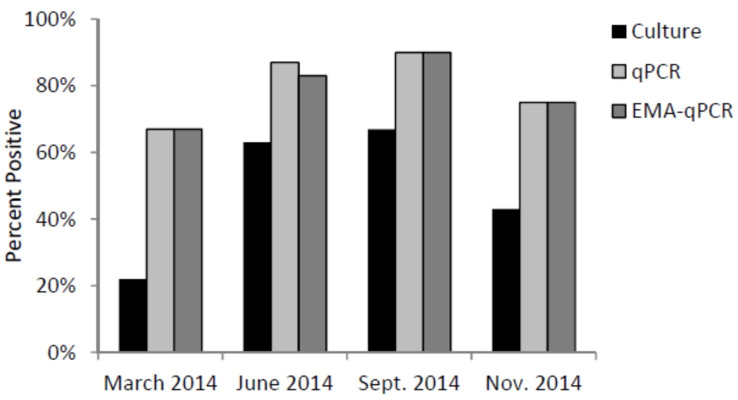
Study design & utility characteristics

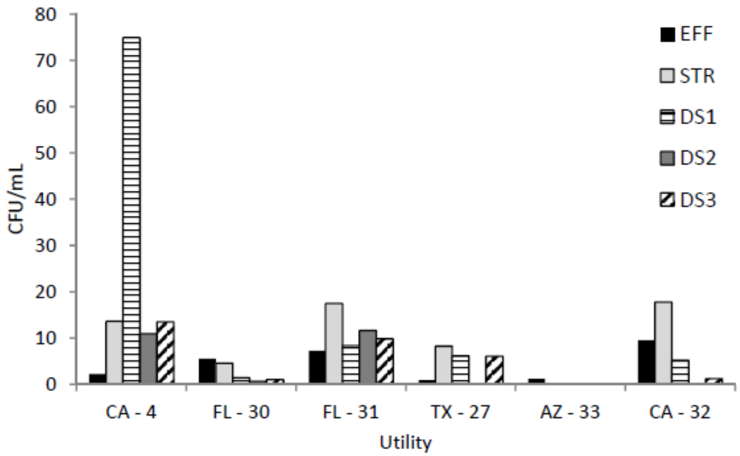
- Survey of 19 United States water utilities during a "snapshot" using a culture-based assay
- Six utilities were followed up quarterly using 3 pathogen detection methods (70% average recovery)

Utility	Treatment Process	Production Capacity (MGD)	Disinfectant	Storage	Length of Distribution System (miles)	Average Residence Time (hours)		
						DS1	DS2	DS3
TX - 27	Activated Sludge, tertiary sand filtration	75	Chlorine	Closed	16	24	55	127
FL - 30	Secondary clarification, sand filtration	7	Chlorine	Open	36	0.25	10	29
CA - 4	Trickling Filter with tertiary sand filtration	0.24	Chlorine	Open	0.3	2	4	5
FL - 31	Activated Sludge, cloth filtration	14	Chlorine	Closed	10	14	17	19
CA - 32	Activated Sludge, tertiary anthracite filtration	40	Chloramine	Closed	100	1	24	48
AZ - 33	Activated Sludge, BNR, tertiary anthracite filtration	10	Chlorine	Closed	130	5	10	24

Occurrence of *Legionella* in reclaimed water

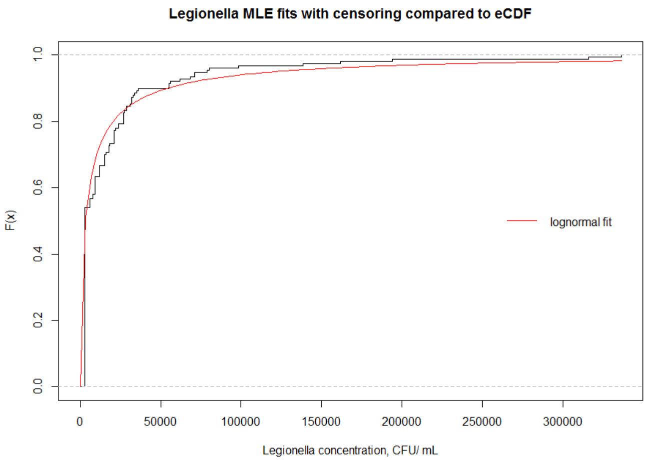
Method	n	*Legionella* spp. (#/mL) in positive samples [Mean ± SD (range)]	% Positive
Culture	153	25 ± 19 (3 - 80)	48
EMA-qPCR	115	307 ± 336 (2 - 1,438)	89
qPCR	115	1,014 ± 683 (1 - 2,550)	90





Occurrence of *L. pneumophila* in reclaimed water

- *Legionella* species identified by serotyping cultured colonies and DNA sequencing qPCR amplification products
  - 16 species identified
  - 96% LP by culture, 52% LP by qPCR



Species	Pathogenic
L. pneumophila	Yes
L. oakridgensis	Yes
L. moravica	No
L. longbeachae	Yes
L. hackeliae	Yes
L. parisiensis	Yes
L. steigerwaltii	Yes
L. anisa	Yes
L. tucsonensis	Yes
L.waltersii	Yes
L. wadsworthii	Yes
L. feeleii	Yes
L. spiritensis	Yes
L.cincinatiensis	Yes
L. lansingensis	Yes
L. jordansis	Yes

A need to assess the health risks from opportunistic pathogens *L. pneumophila* in reclaimed water

Pathogens present? ☑

Potential for exposure? ☑

What are the risks? ☐

Table 2. Typical uses of recycled water for 10 systems in the US and related potential to generate aerosols.

Use	System (%) [1]	Potential for Generating Aerosols
Irrigation (parks, medians, farms, lawns, *etc.*)	90	Low (drip) to high (aerial spray)
Cooling towers/Boilers	50	High
Construction	20	Moderate
Dust control	10	Moderate
Washing (cars, windows)	10	Moderate
Street sweeping	10	Moderate
Fire fighting	10	Moderate
Toilet/Urinal flushing	30	Low
Groundwater recharge	20	Low
Animal watering	10	Low
Wetlands	10	Low

[1] Total is more than 100% as most systems utilized recycled water for multiple uses. Source: Table compiled from [25].

Jjemba et al. 2015 *Pathogens*

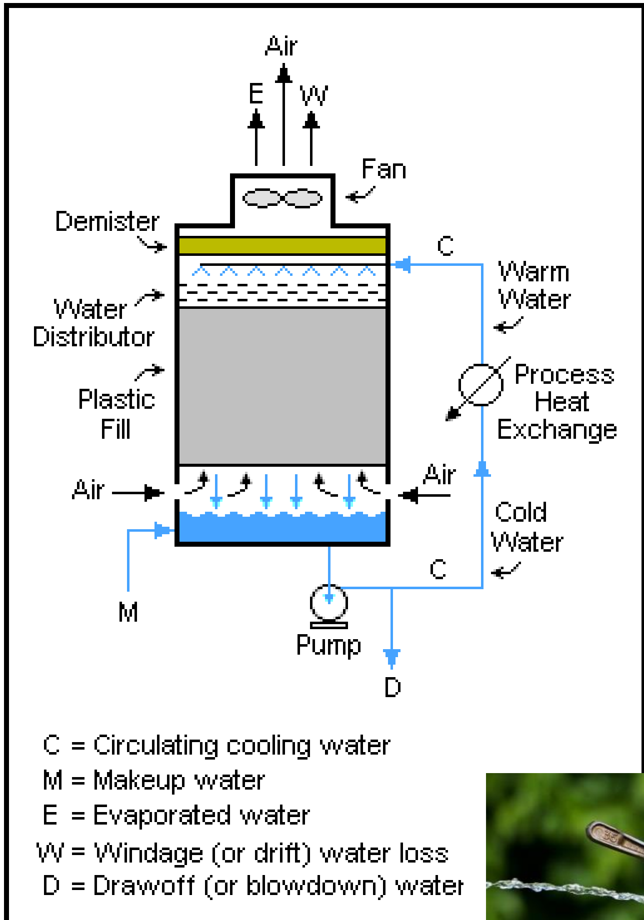
survey responses

331 plant operators from 7 countries

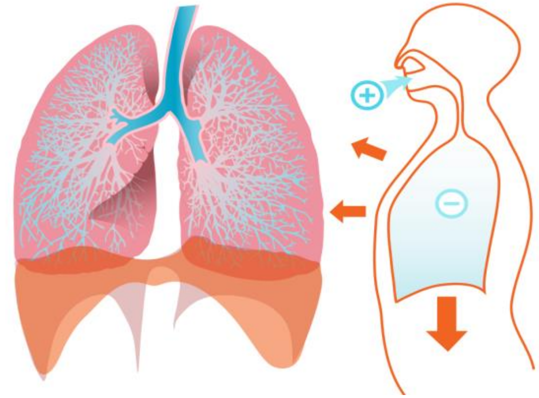
Sprinklers identified in survey

Irrigation sprayer	Device height (m)	Recommended pressure range (kPa)	Flow rate (L/s)	Spray radius (m)	Max stream height (m)	Distance to max spray height (m)
Rainbird Eagle 900	0.09	410-690	1.35-3.60	19.2-29.6	6.1	18.3-24.4
Rainbird Eagle 700	0.07- 0.31	410-690	1.03-2.76	10.7-22.9	5.2	8.2-19.8
Toro 800 series	0.15-0.432	200-350	0.03-0.63	9.7-15.2	NA	NA
Hunter Pro-Spray (spray head)	0.05-0.3	100-700	0.01-0.36	2.6-5.8	NA	2.2-4.5
Hunter PGP Rotors 4’’	0.10 (total device height 0.19)	206-482	0.032-0.91	6.7-15.9	2.1-4.0	6.7-12.2

Exposure scenarios

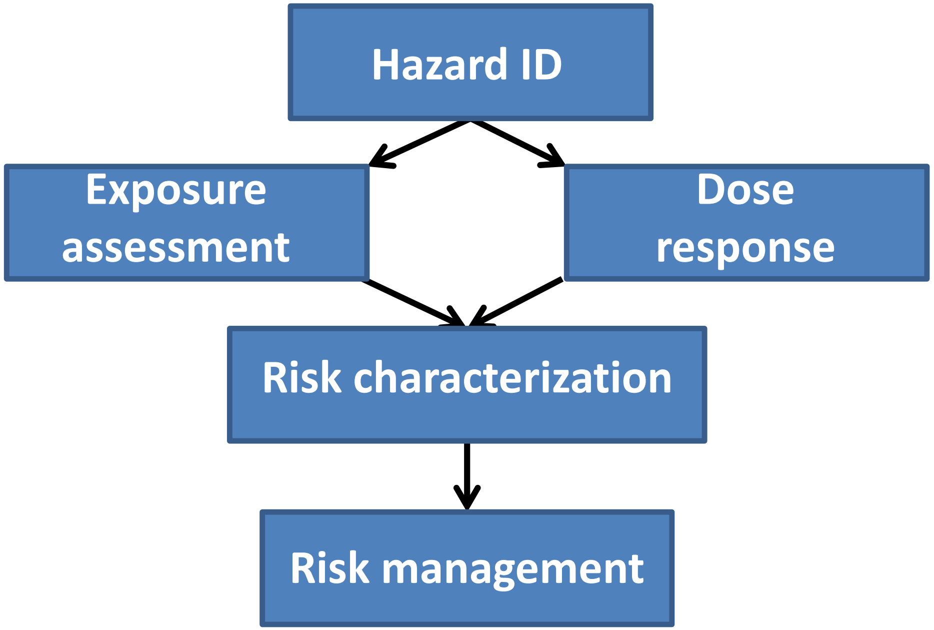


Source

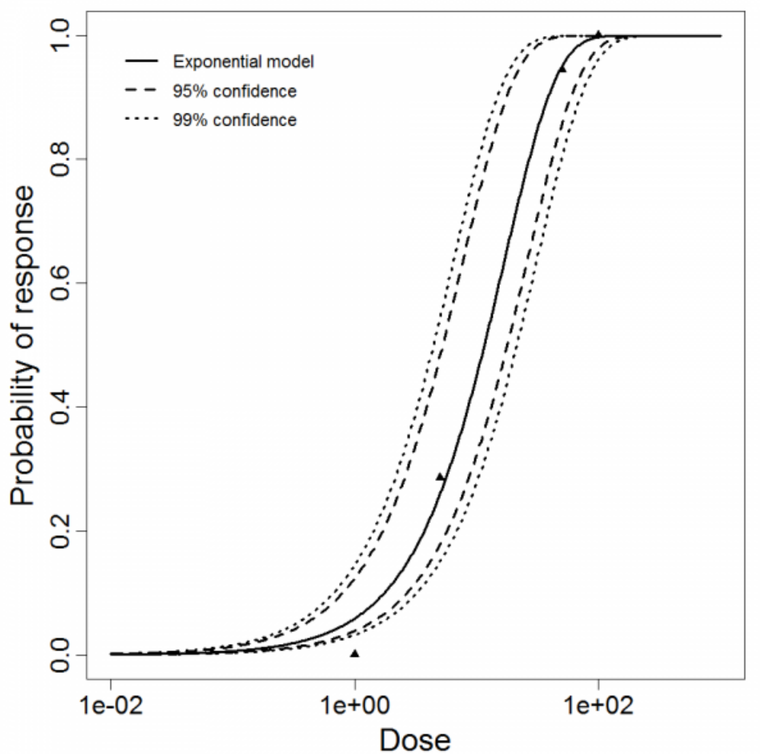


Aerosol inhalation

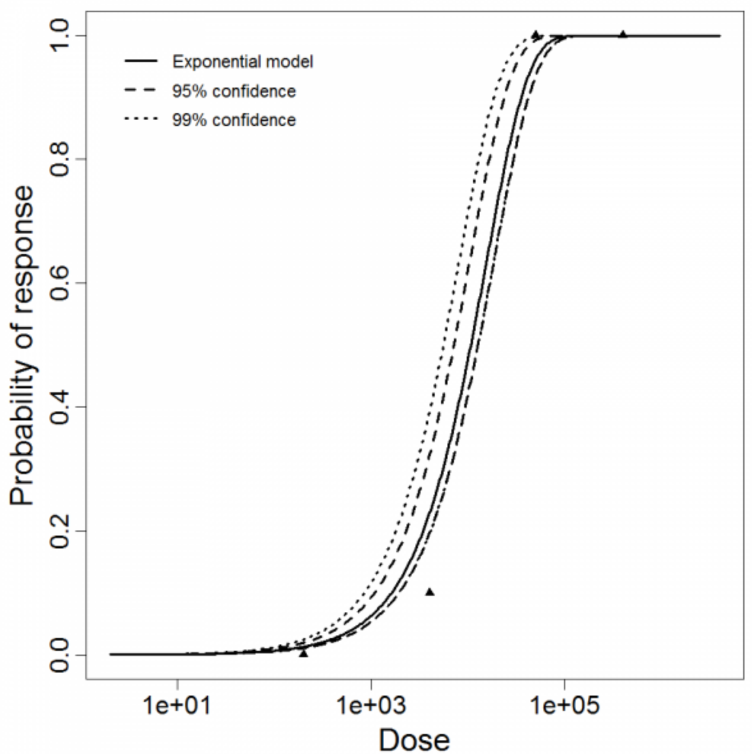
QMRA framework



L. pneumophila dose response model: subclinical infection vs. clinical severity infection (CSI)- Armstrong & Haas 2007



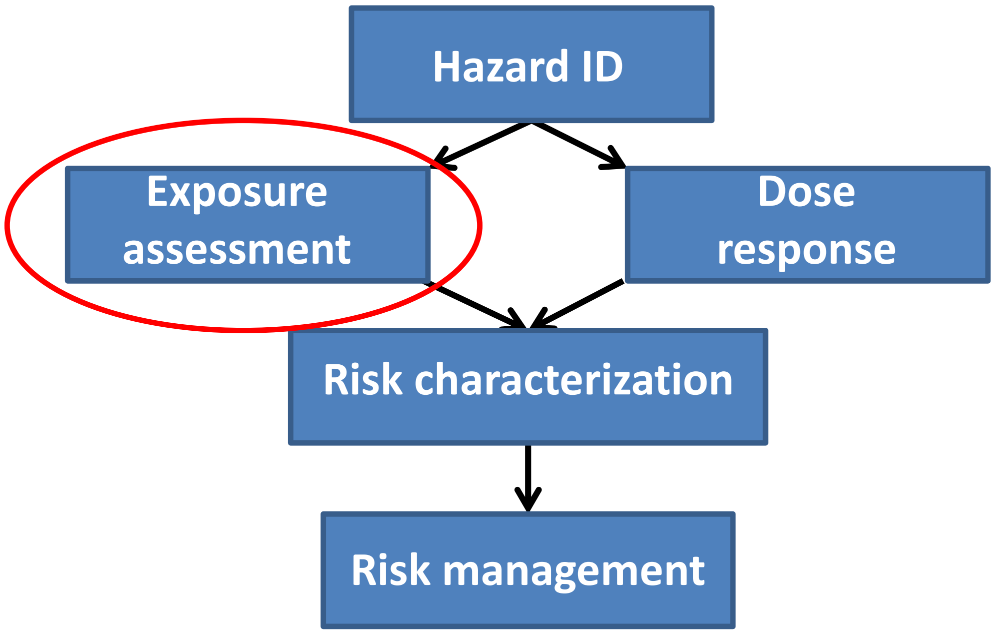
Pulmonary infection –"**infection**"
Inhalation route (Baskerville et al. 1981)
Guinea pigs
$r = 6 \times 10^{-2}$
ID_{50} = 11.6 CFU



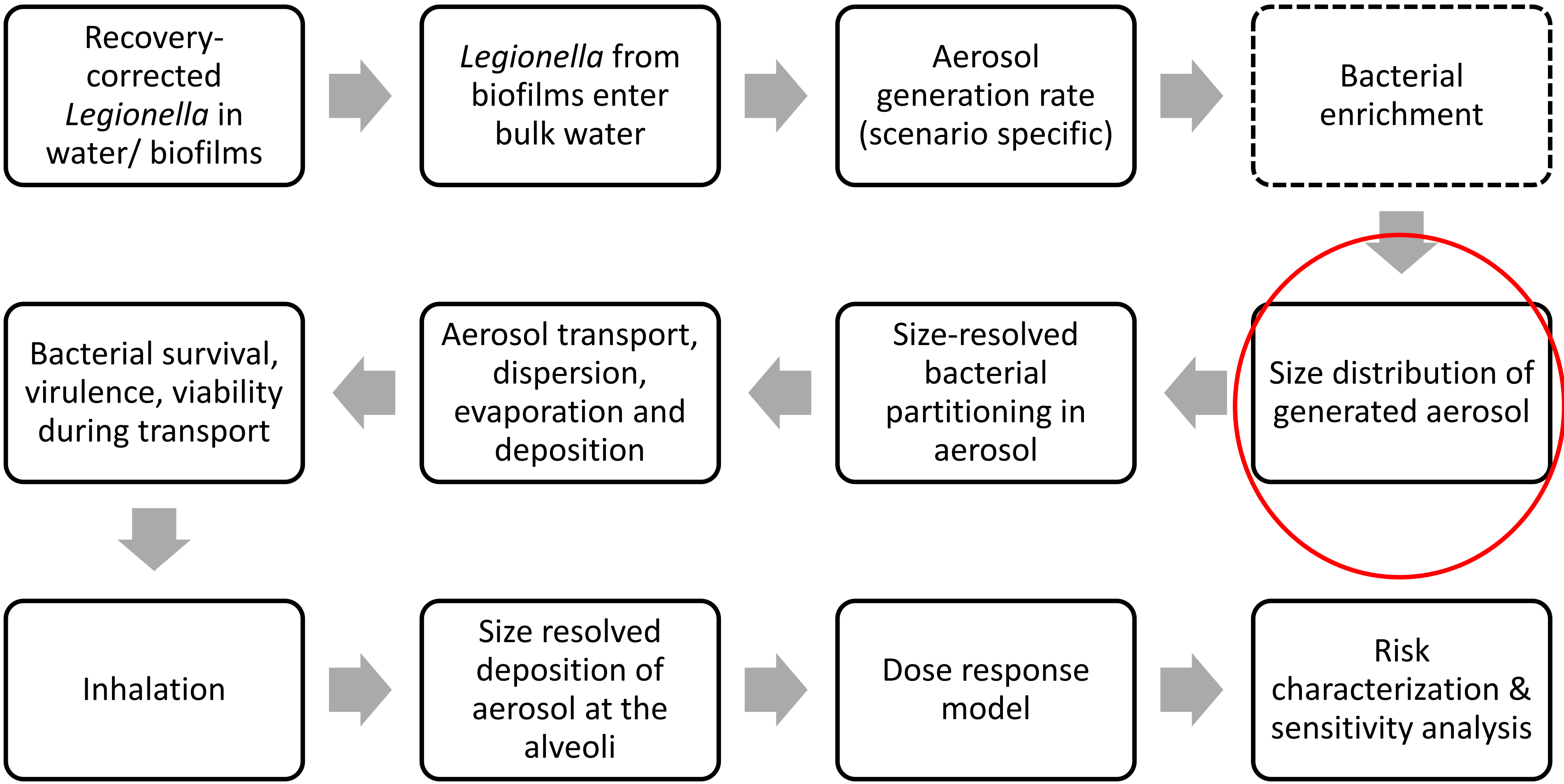
Death- "**clinical severity infection**"
Inhalation route (Muller et al. 1983)
Mice
$r = 6.48 \times 10^{-5}$
$ID_{50} = 1.07 \times 10^{4}$ CFU

http://qmrawiki.canr.msu.edu

QMRA framework



Legionella risk assessment process



Hamilton & Haas, 2016

Exposure models for spray irrigation & recirculating non-contact cooling towers: emission rate

$$Q_{Leg} = CL_{egFE}$$

Q_{Leg} = emission rate of *L. pneumophila* [#/ min]

C_{Leg}= Concentration of *L. pneumophila* in reclaimed water [#/L]

F= flow rate[L/s]

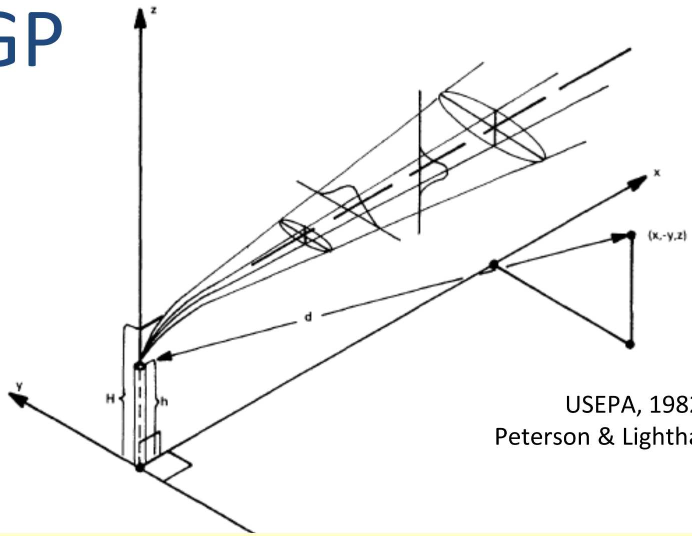
E= aerosolization efficiency= fraction of sprayed reclaimed water that leaves the immediate vicinity of system as aerosols (0<E≤1)

CT Normal operating conditions: 0.001-0.005 % drift loss (ASHRAE)

CT "Bad" operating conditions: 0.1-0.01 % (Lucas et al. 2012)

Sprinkler: 0.5 – 1.4 % (Kohl et al. 1974)

Exposure models for spray irrigation & recirculating non-contact cooling towers: GP



USEPA, 1982,
Peterson & Lighthart 1977

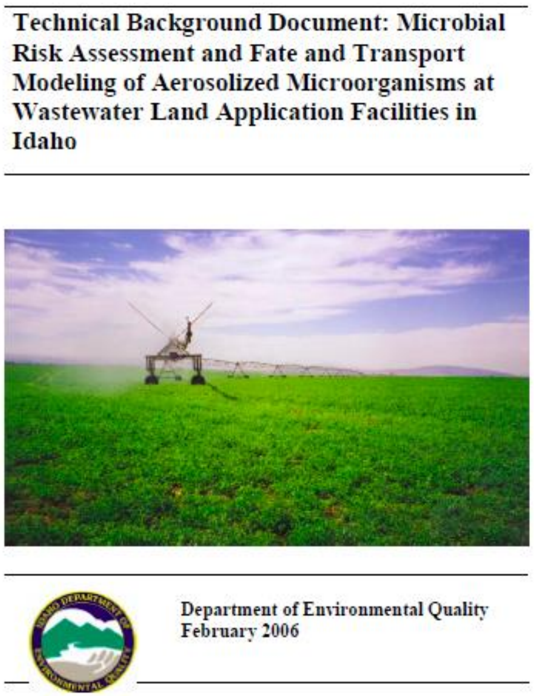
$$Dose(x,y,z) = \frac{Q_{Leg} It}{2\Pi \mu \sigma_y \sigma_z} \exp\left[\left(\frac{-y}{2\sigma_y}\right)^2\right]\left\{exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right]\right\} \sum_{i=1}^{n} q_{i,s} DE_i exp^{\frac{-\lambda_s x}{\mu}}$$

D_{Leg} = Dose of *Legionella* at *x*, *y*, and *z* meters downwind from the source

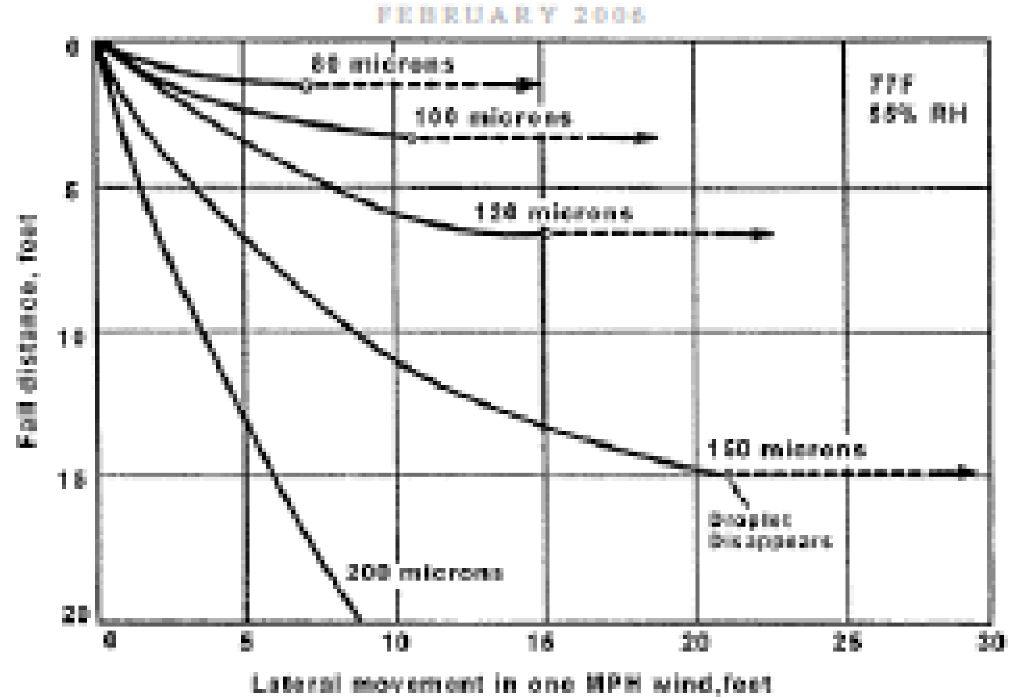
x = distance downwind (m)
y = horizontal distance perpendicular to wind (m)
z = downwind receptor breathing zone height (1.5 m)
H = source height (m)
μ = wind velocity (m/s)
σ_y = horizontal dispersion coefficient (m)
σ_z = vertical dispersion coefficient (m)

λ= Decay rate (s^{-1}) for state *s*
s = in aqueous aerosol or evaporated
I= inhalation rate (m^3 / min);
t= is the exposure duration (min)
$q_{i,s}$ = mass-weighted proportion of diameter 1 through 10 µm in the evaporated or aqueous aerosol state *s* (assumed to be uniform fractions)

Aerosol size assumptions: 100 and 200 µm fractions

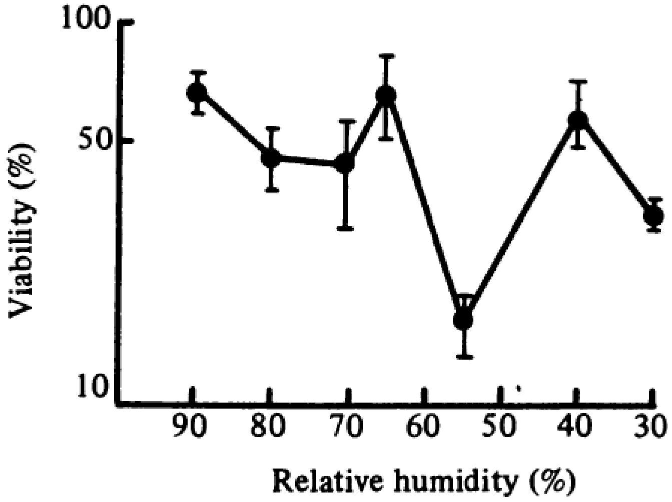

Technical Background Document: Microbial Risk Assessment and Fate and Transport Modeling of Aerosolized Microorganisms at Wastewater Land Application Facilities in Idaho

Department of Environmental Quality
February 2006



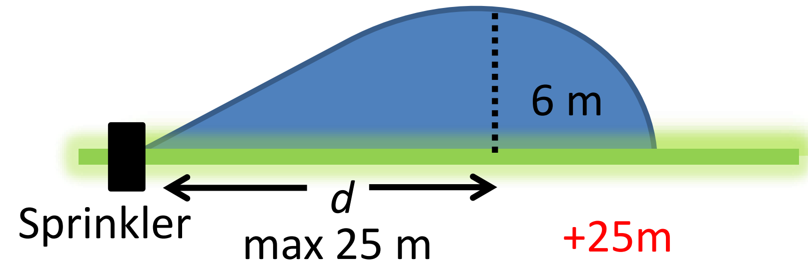
Sprinkler (Rainbird 30 5/32)	0.0138, 0.0413	Hardy et al. 2006 (Idaho DEQ)
Cooling tower	0.0459, 6.03×10^{-4}	Peterson and Lighthart 1977

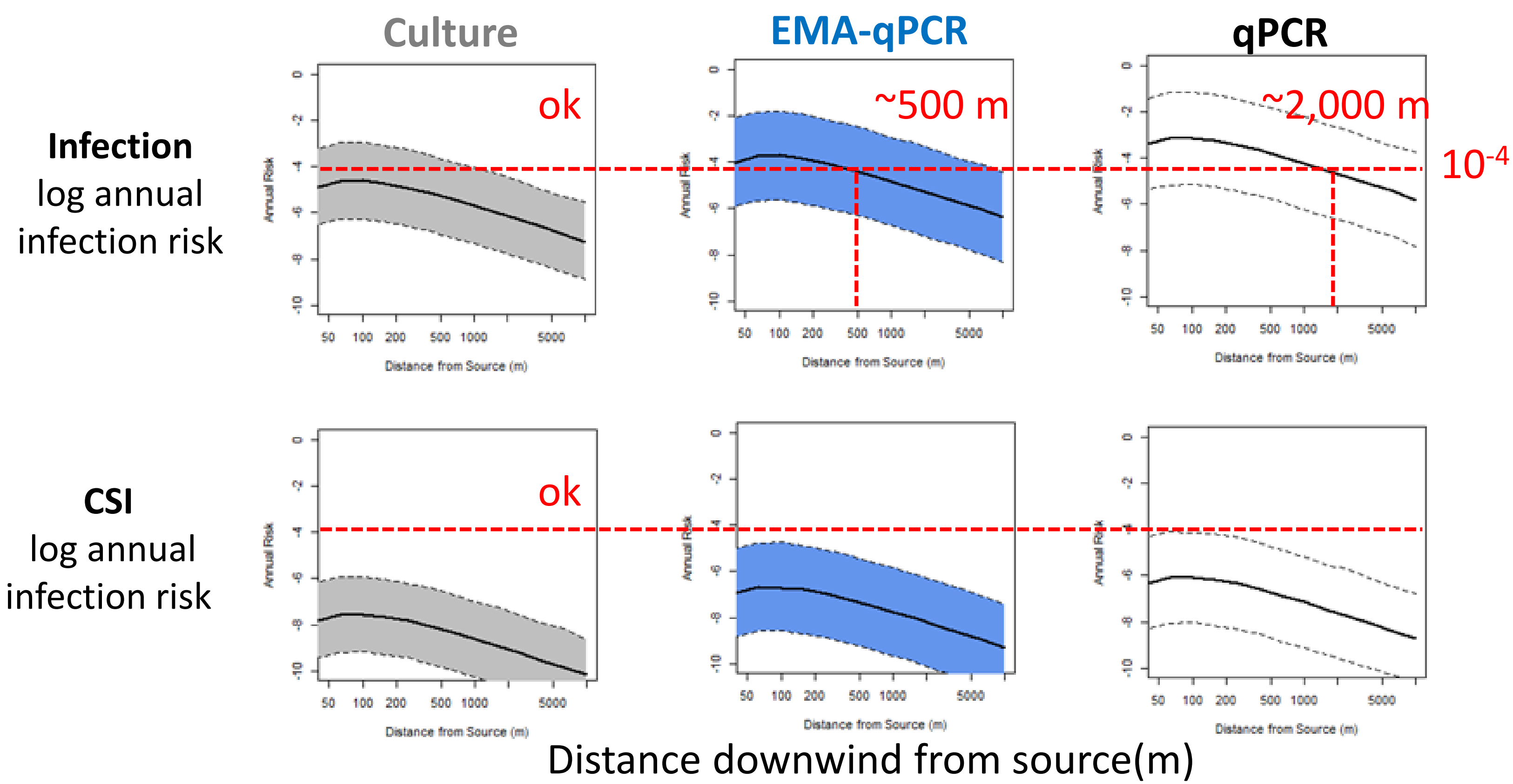
Decay assumptions



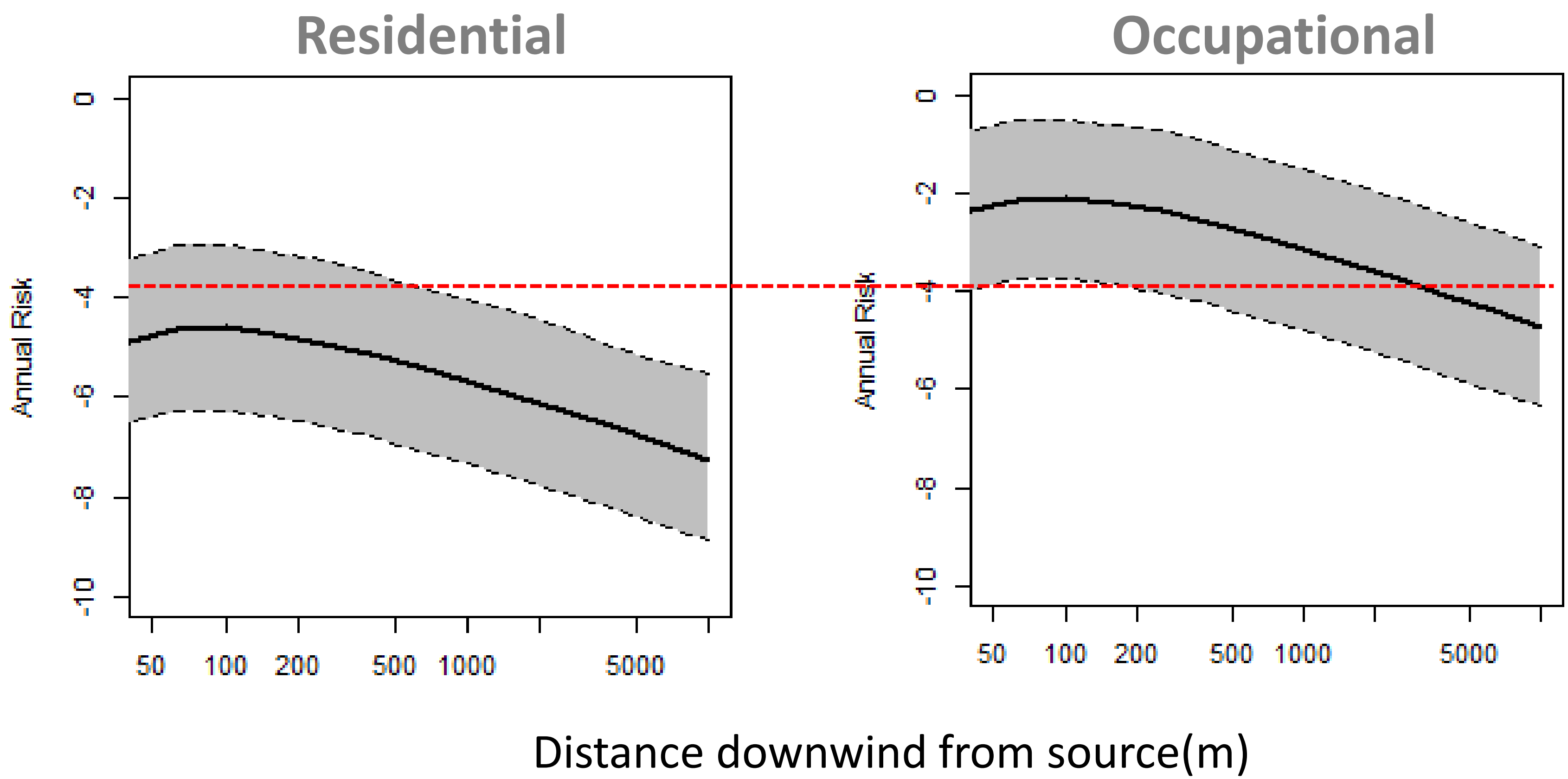
Conditions	Decay (s^{-1})	Reference
RH=65%	8.40×10^{-5}- 2.38×10^{-4}	Hambleton et al. 1983
RH= 80%	1.82×10^{-4}- 3.09×10^{-4}	Berendt 1981 , Dennis 1988
RH=90%	7.88×10^{-5}- 4.09×10^{-4}	Hambleton et al 1983, Dennis and Lee 1988
Evaporated (t_1=up to 30s, t_2= t- 30s if t > 30s)	0.125 3.10×10^{-4}	Katz and Hammel 1987

Sprinkler annual risks modeled for varying conditions





Sprinkler annual risks and the impact of the population at risk

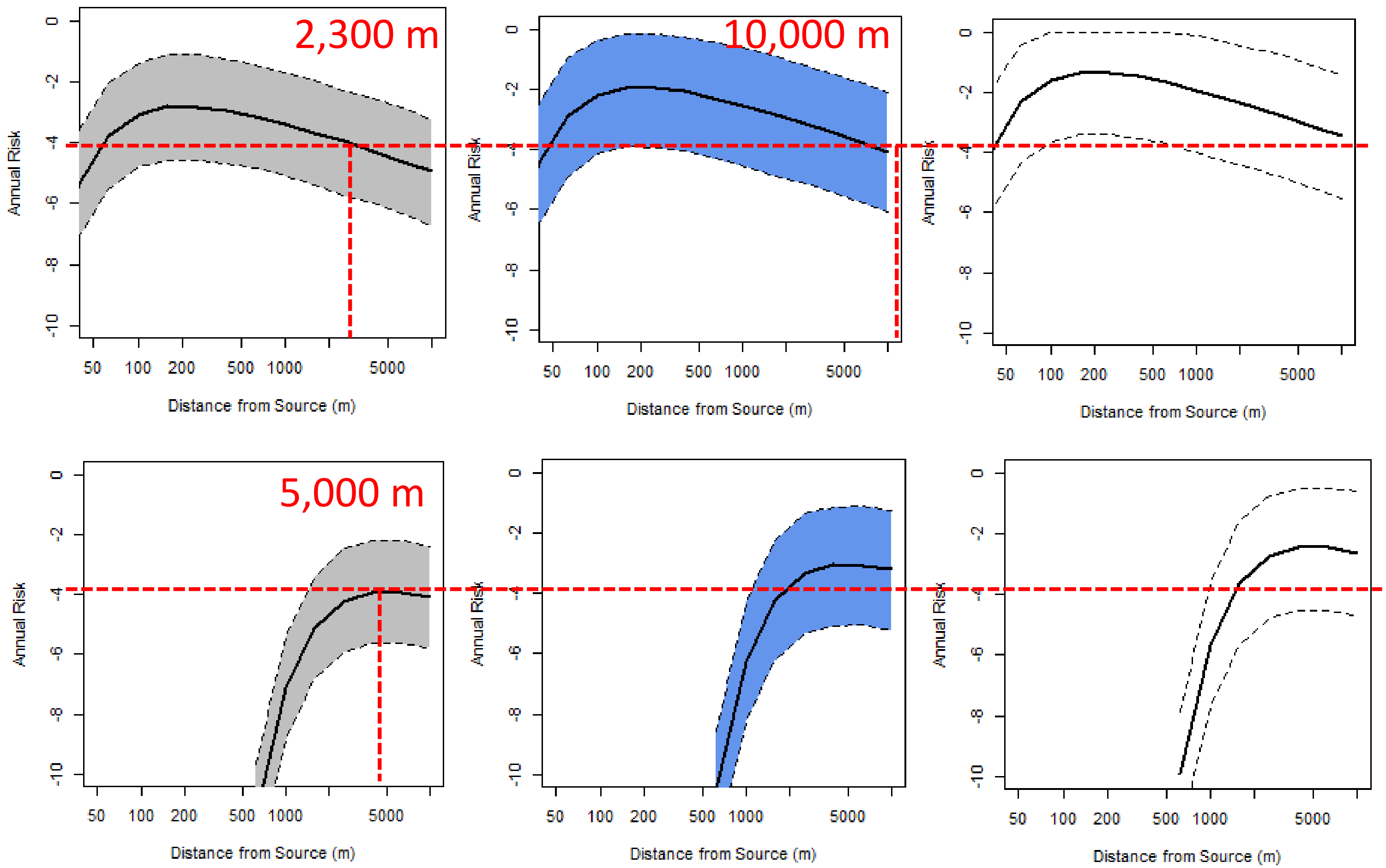


Cooling tower annual risks and impact of stack height

Culture | **EMA-qPCR** | **qPCR**

Height = 10 m

Height = 100 m



Residential log annual infection risk **Efficiency** 0.001-0.005% (good)

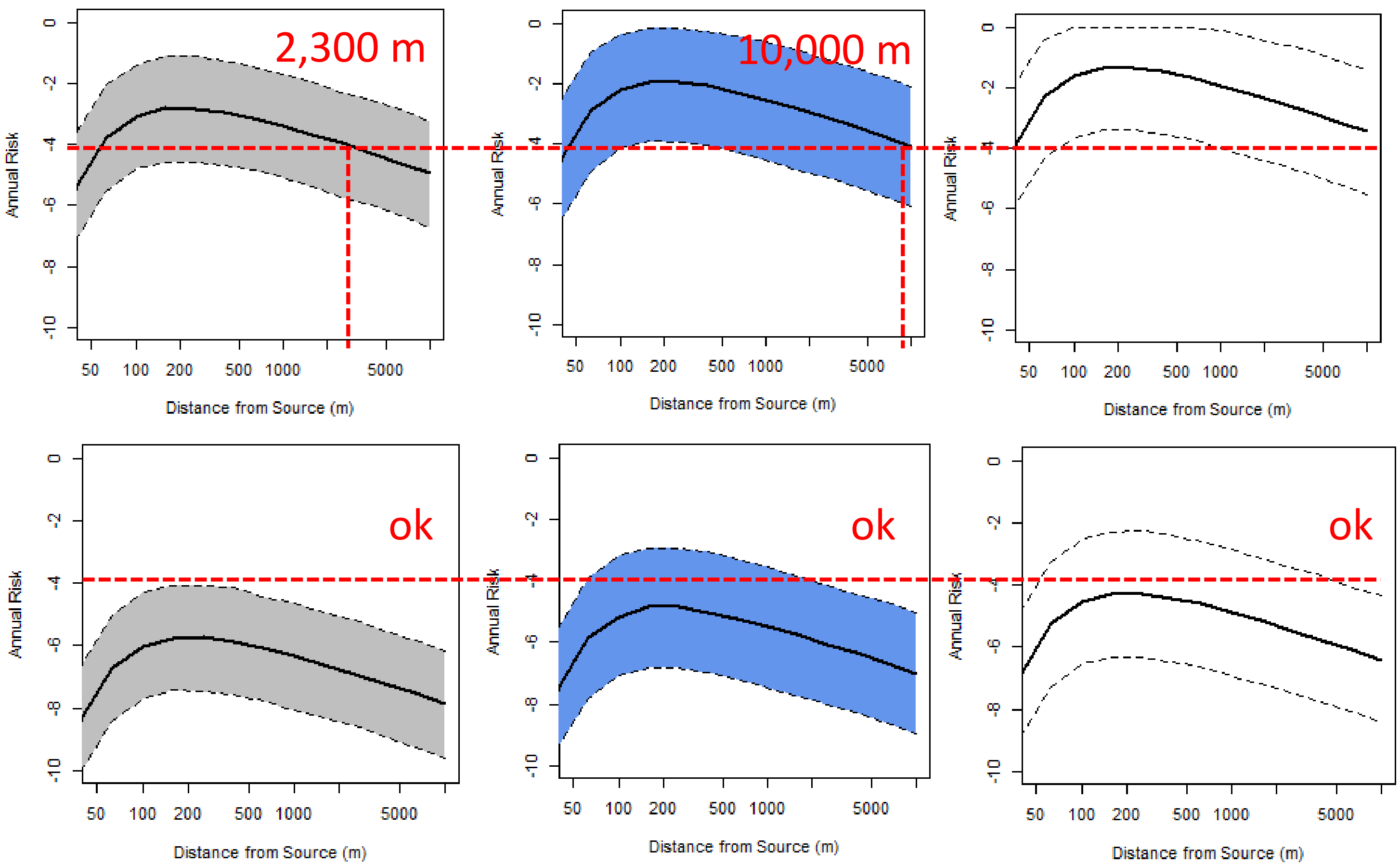
Stack height shift peak downwind- very large setback distances would be needed

Cooling tower annual risks and impact of dose response (stack height = 10 m)

Culture | **EMA-qPCR** | **qPCR**

Infection
Height = 10 m

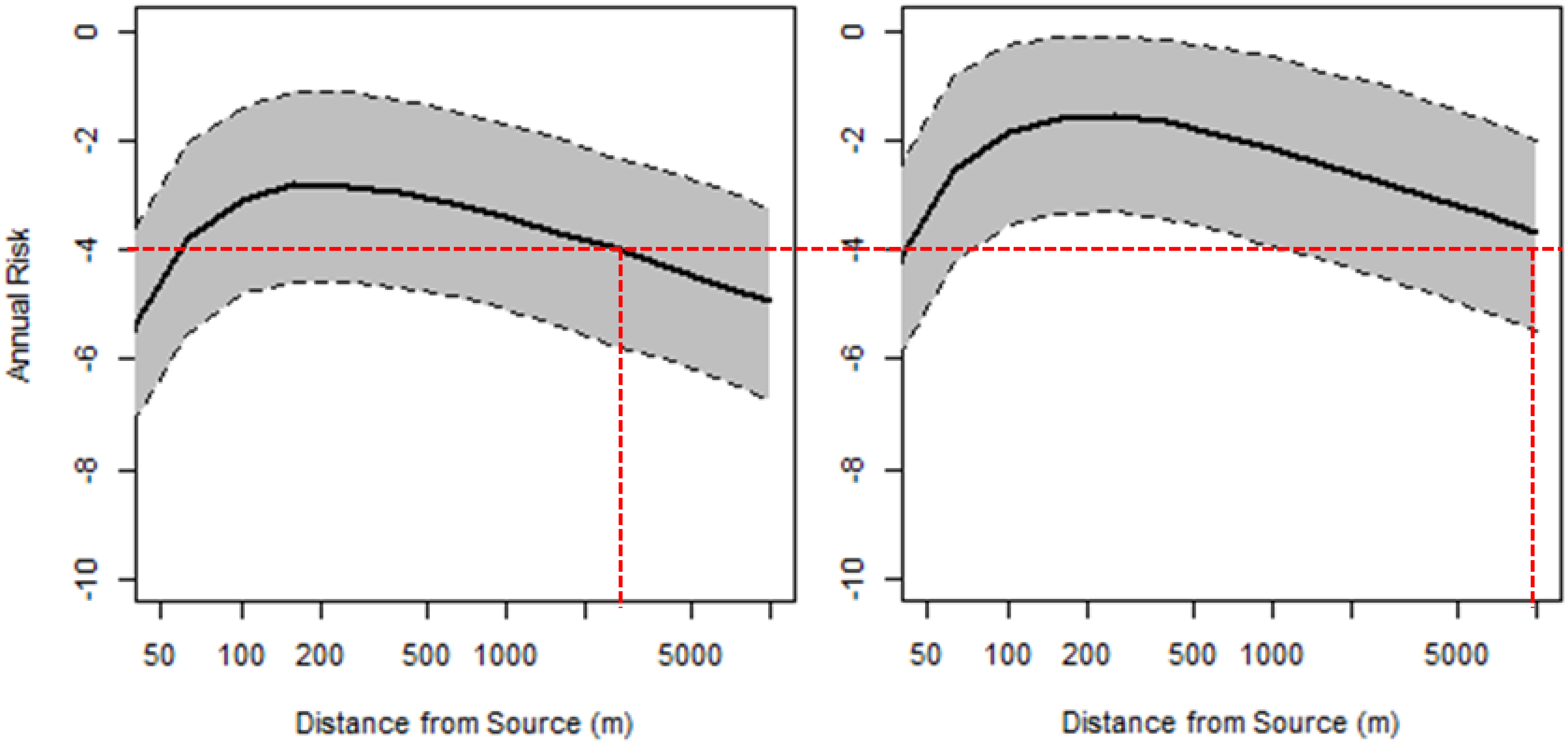
CSI
Height = 10 m



Residential log annual infection risk
Efficiency 0.001-0.005% (good)

Residential log annual infection risk
Efficiency 0.001-0.005% (good)

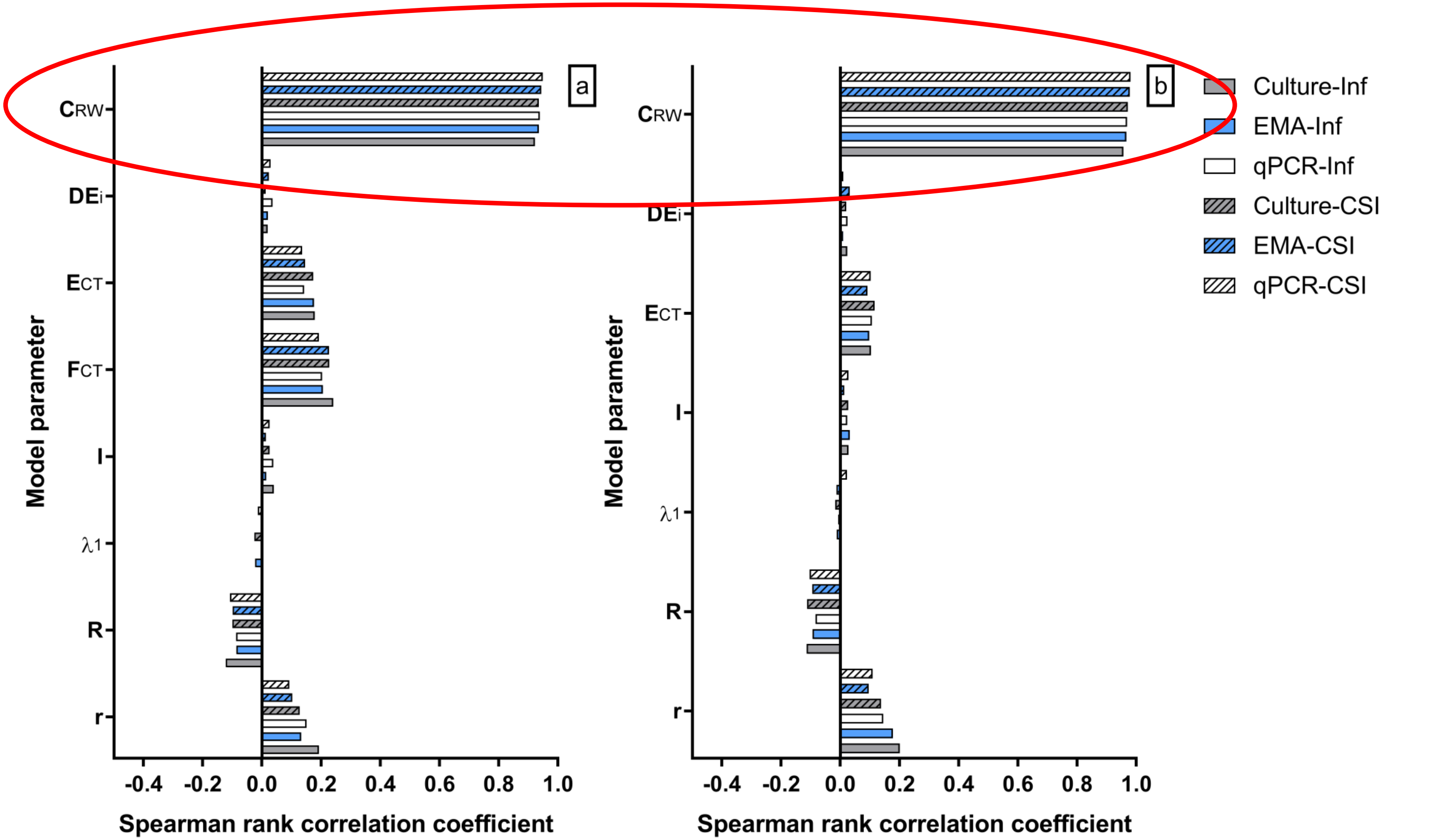
Cooling tower annual risks and impact of cooling tower efficiency



"Normal conditions"
0.001-0.005 % drift

"Bad conditions"
0.1-0.01 % drift

Sensitivity analysis



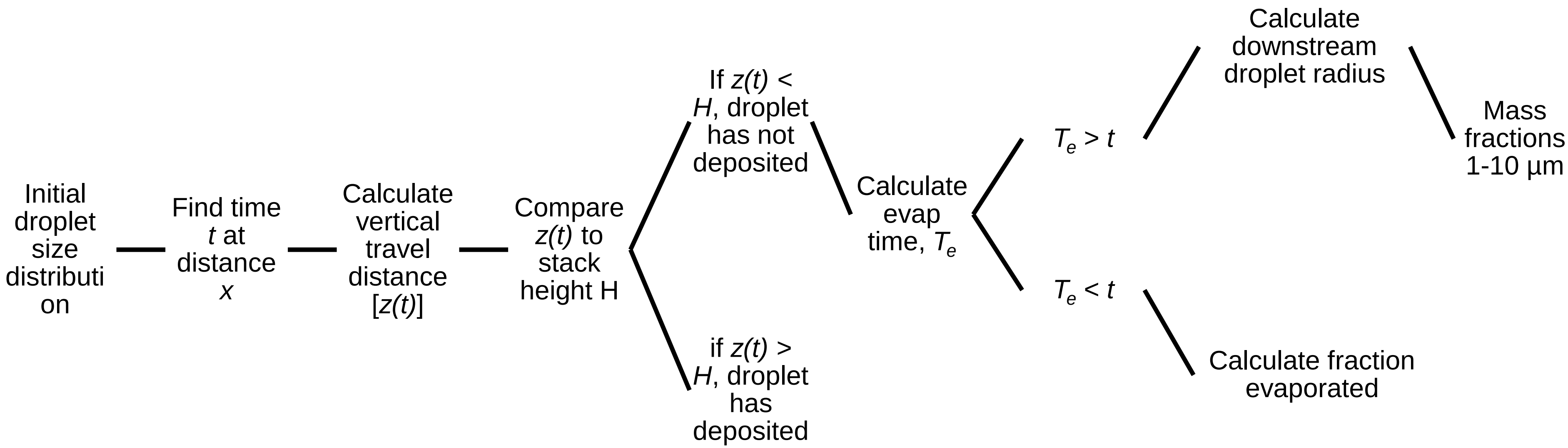
Conclusions

- *Legionella* risks are non-trivial at potentially large distances for spray irrigation and sprinklers
- Risks and setback distance chosen varies depending on:
  - Dose response model chosen
  - Population at risk
  - Detection method
  - Operating conditions (drift eliminator performance)
  - Stack height (CT)
  - meteorological conditions
- Concentration of *Legionella* most influential model parameter in all models
- Other management practices can be applied to reduce setback distances needed

Limitations and data gaps

- No solar inactivation – a data gap
- Does not account for time-activity patterns
- Protection of *Legionella* due to the presence of organic debris or algae is not considered- **no regrowth up to point of use**
- Impacts of aerosol dynamics including bubble burst, break up or agglomeration of aerosols, film collapse, and shear forces on *Legionella* are not considered
- No topographic effects
- No plume rise
- Need to incorporate biofilm, algae, organic debris impacts
- Fate of bacteria in individual aerosols is not tracked
- Enrichment not considered
- No blending with any other water source prior to use

Next steps: Aerosol size model- the "q"



Thank you

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