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SCHOOL OF PUBLIC HEALTH

Assessing the enteric pathogen risk within Natural Swimming Pools

Case study: Borden Park, Edmonton, Canada

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Acknowledgments

- **Nicholas ASHBOLT** Professor and Alberta Innovates Translational Research Chair in Waterborne Disease Prevention – Ashbolt@Ualberta.ca
- **Drs Qiaozhi Li & Sydney Rudko**
- **SPH lab staff: David Shoults, Candis Scott, Lena Dlusskaya & Dr. Mats Leifels**
- **City of Edmonton staff, let by Cyndi Schlosser**

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ALBERTA INNOVATES

Overview

- Introduction: illness and freshwater recreation
- What causes illness? Pathogens of concern in recreational environments
- How is water quality managed? Regulatory frameworks
- What is a risk based approach to managing recreational water safety?
- What is Quantitative Microbial Risk Assessment (QMRA)
- Application of QMRA Boden Park NSP, Edmonton, Canada

Illness and freshwater recreation

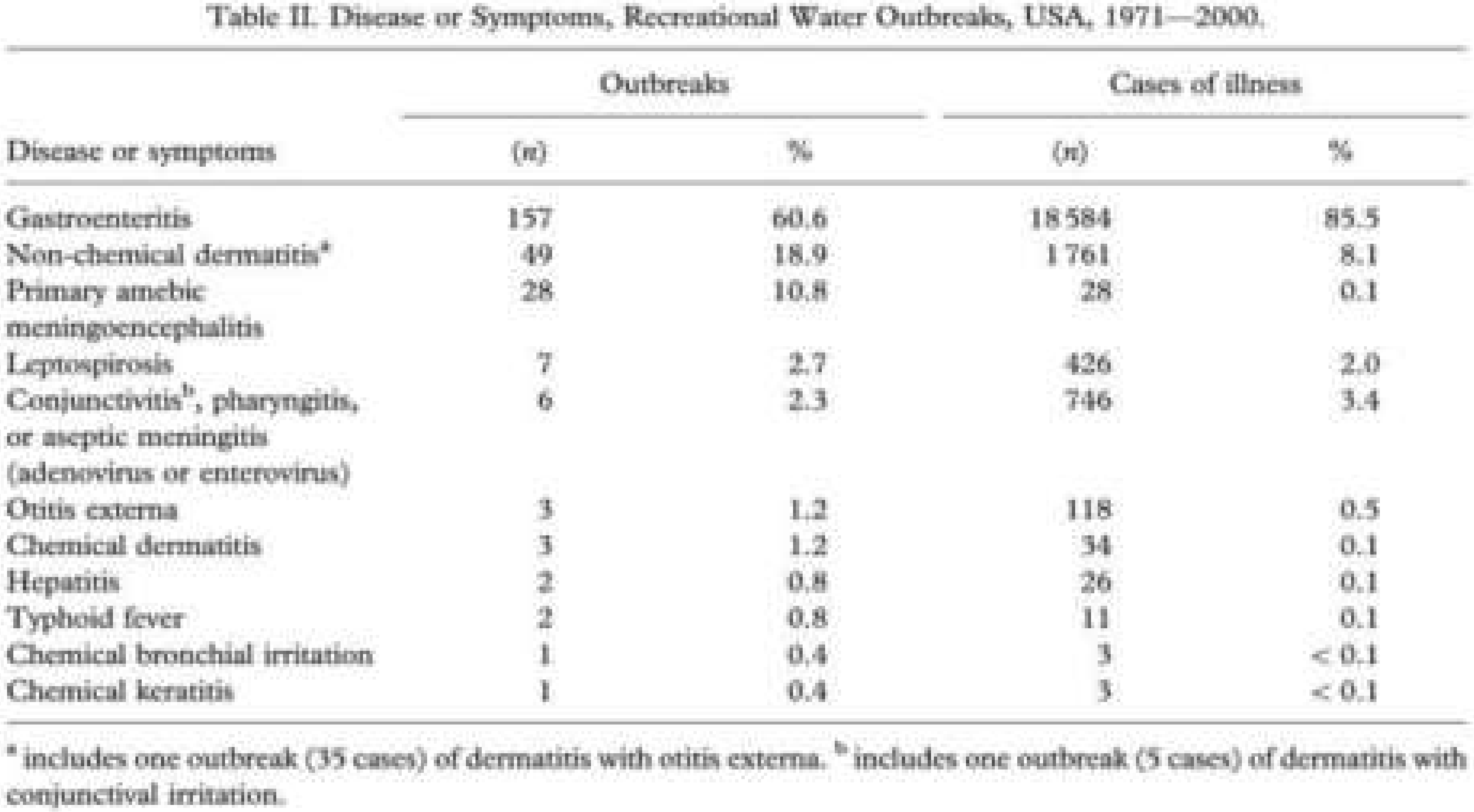


Table II. Disease or Symptoms, Recreational Water Outbreaks, USA, 1971—2000.

	Outbreaks		Cases of illness	
Disease or symptoms	(*n*)	%	(*n*)	%
Gastroenteritis	157	60.6	18 584	85.5
Non-chemical dermatitis[a]	49	18.9	1 761	8.1
Primary amebic meningoencephalitis	28	10.8	28	0.1
Leptospirosis	7	2.7	426	2.0
Conjunctivitis[b], pharyngitis, or aseptic meningitis (adenovirus or enterovirus)	6	2.3	746	3.4
Otitis externa	3	1.2	118	0.5
Chemical dermatitis	3	1.2	34	0.1
Hepatitis	2	0.8	26	0.1
Typhoid fever	2	0.8	11	0.1
Chemical bronchial irritation	1	0.4	3	< 0.1
Chemical keratitis	1	0.4	3	< 0.1

[a] includes one outbreak (35 cases) of dermatitis with otitis externa. [b] includes one outbreak (5 cases) of dermatitis with conjunctival irritation.

Craun*, G. F., Calderon, R. L., & Craun, M. F. (2005). Outbreaks associated with recreational water in the United States. *International journal of environmental health research*, *15*(4), 243-262.

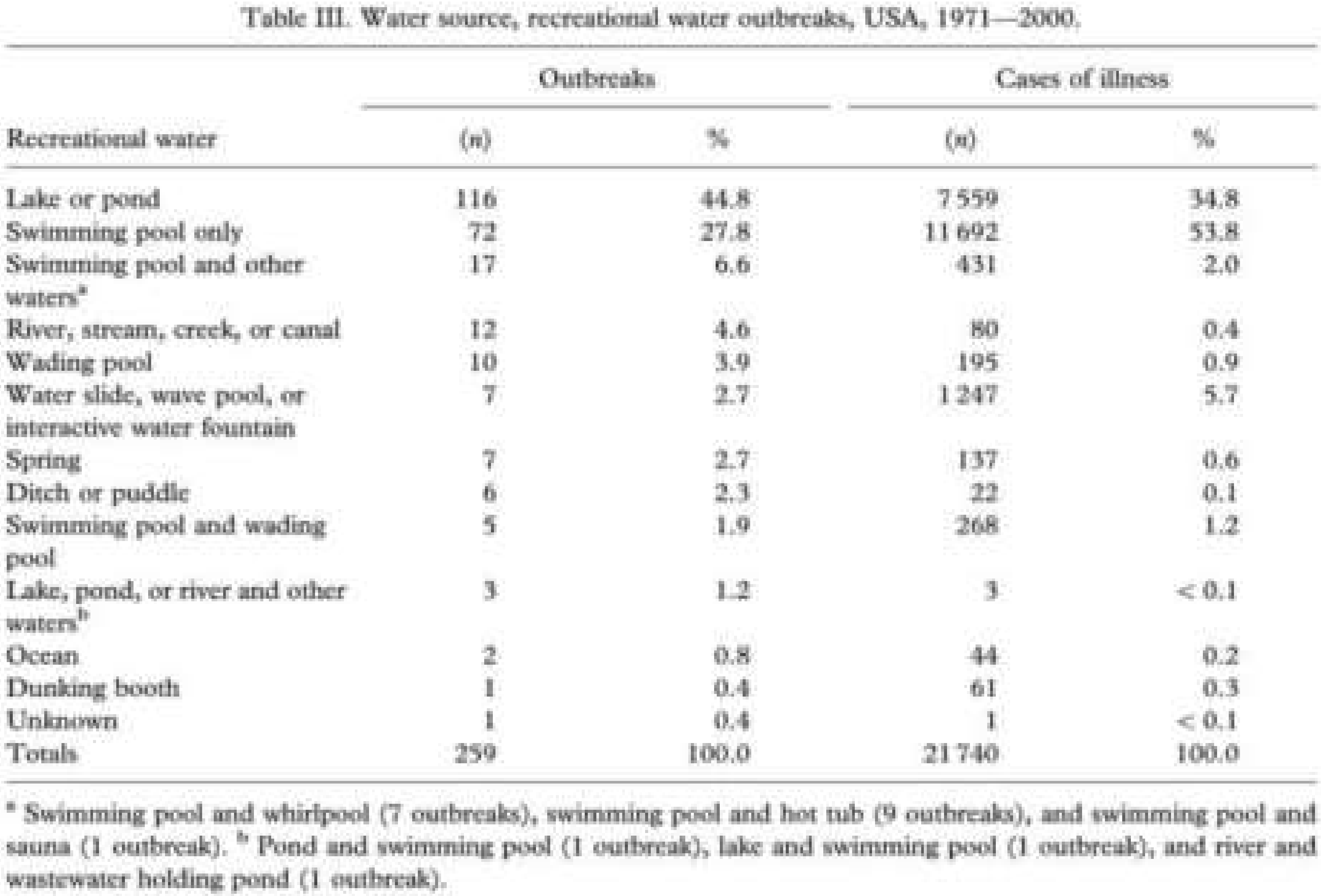


Table III. Water source, recreational water outbreaks, USA, 1971—2000.

	Outbreaks		Cases of illness	
Recreational water	(*n*)	%	(*n*)	%
Lake or pond	116	44.8	7 559	34.8
Swimming pool only	72	27.8	11 692	53.8
Swimming pool and other waters[a]	17	6.6	431	2.0
River, stream, creek, or canal	12	4.6	80	0.4
Wading pool	10	3.9	195	0.9
Water slide, wave pool, or interactive water fountain	7	2.7	1 247	5.7
Spring	7	2.7	137	0.6
Ditch or puddle	6	2.3	22	0.1
Swimming pool and wading pool	5	1.9	268	1.2
Lake, pond, or river and other waters[b]	3	1.2	3	< 0.1
Ocean	2	0.8	44	0.2
Dunking booth	1	0.4	61	0.3
Unknown	1	0.4	1	< 0.1
Totals	259	100.0	21 740	100.0

[a] Swimming pool and whirlpool (7 outbreaks), swimming pool and hot tub (9 outbreaks), and swimming pool and sauna (1 outbreak). [b] Pond and swimming pool (1 outbreak), lake and swimming pool (1 outbreak), and river and wastewater holding pond (1 outbreak).

Craun*, G. F., Calderon, R. L., & Craun, M. F. (2005). Outbreaks associated with recreational water in the United States. *International journal of environmental health research*, *15*(4), 243-262.

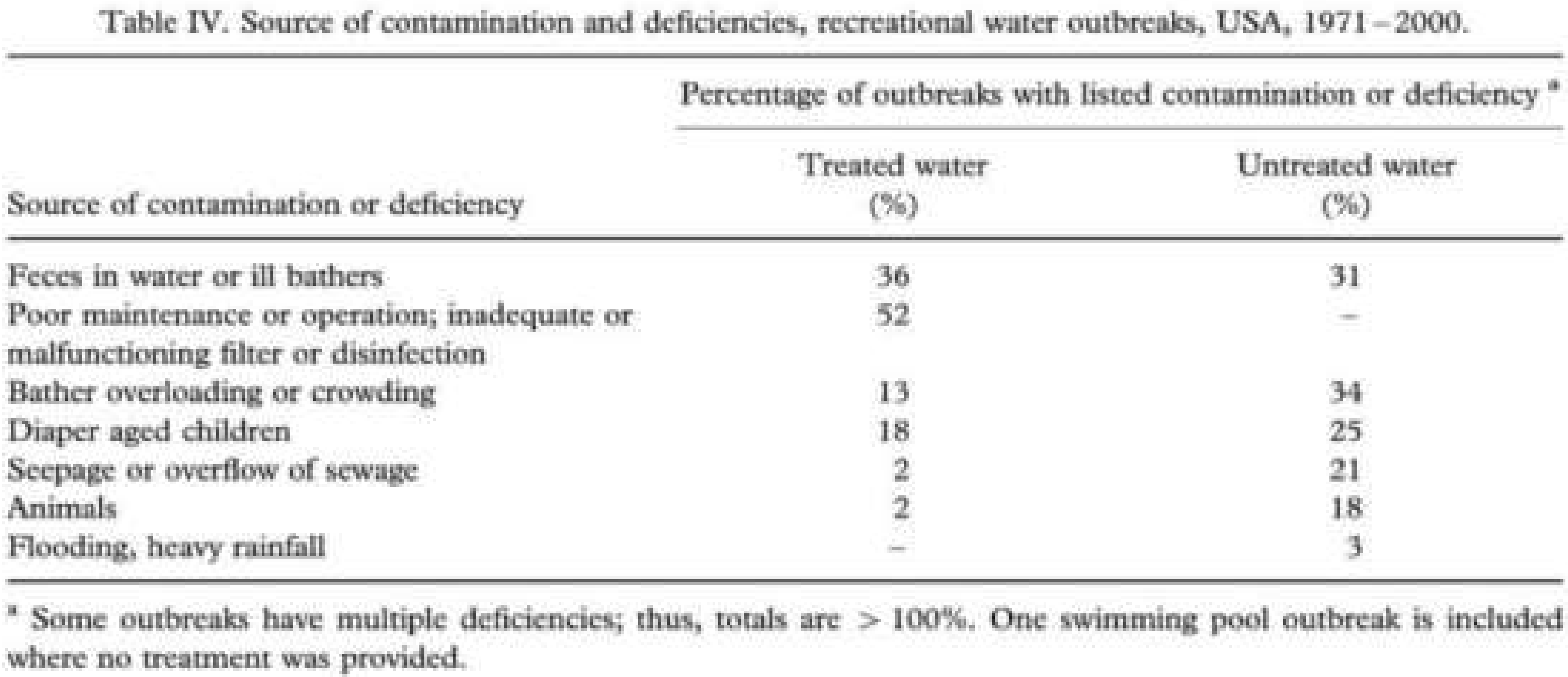
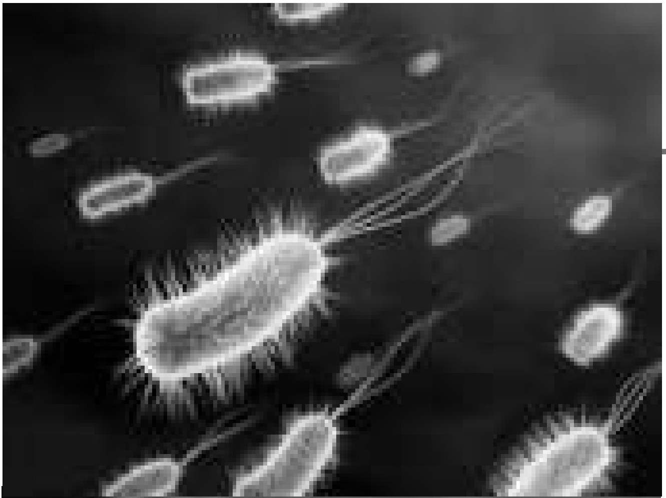


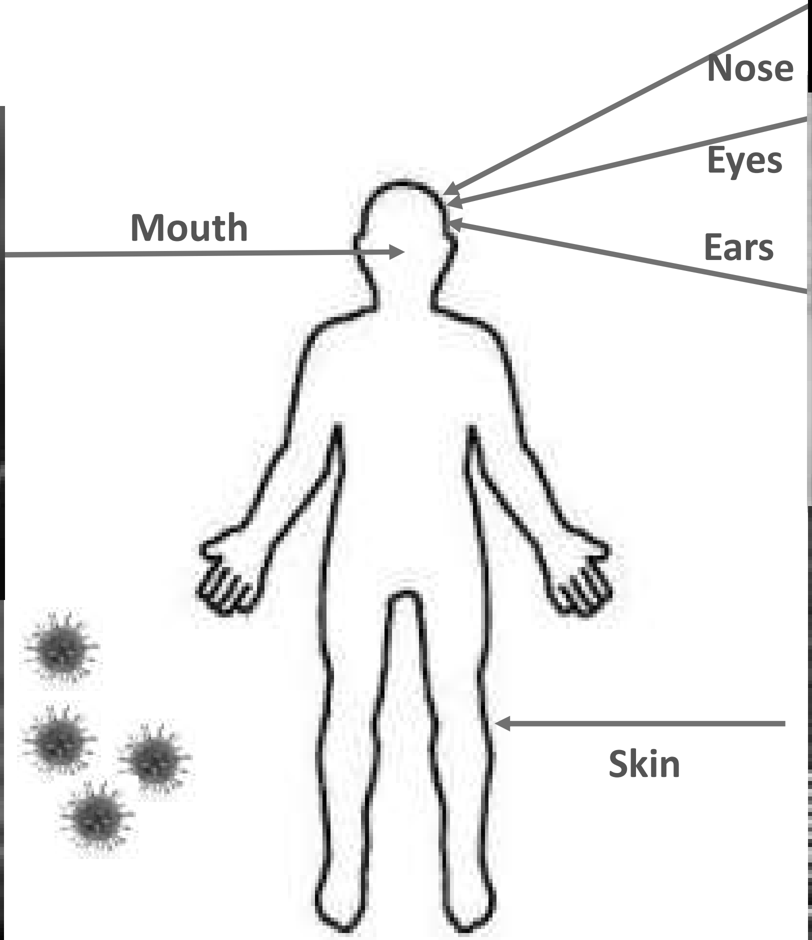
Table IV. Source of contamination and deficiencies, recreational water outbreaks, USA, 1971–2000.

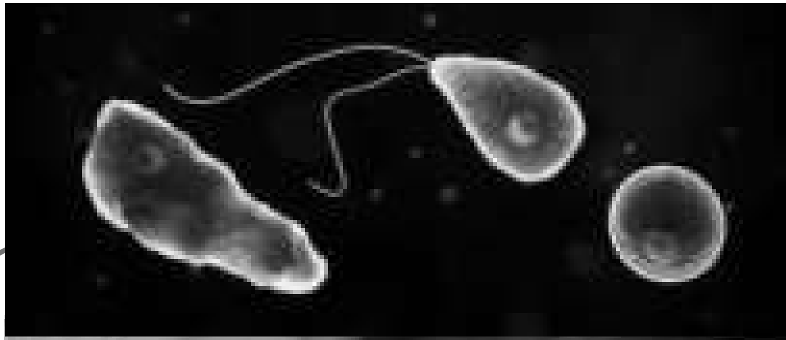
Source of contamination or deficiency	Percentage of outbreaks with listed contamination or deficiency *	
	Treated water (%)	Untreated water (%)
Feces in water or ill bathers	36	31
Poor maintenance or operation; inadequate or malfunctioning filter or disinfection	52	–
Bather overloading or crowding	13	34
Diaper aged children	18	25
Seepage or overflow of sewage	2	21
Animals	2	18
Flooding, heavy rainfall	–	3

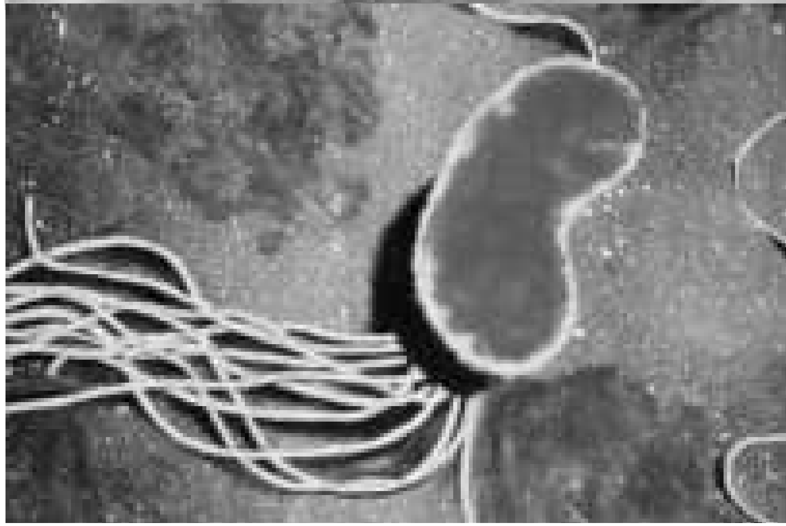
* Some outbreaks have multiple deficiencies; thus, totals are > 100%. One swimming pool outbreak is included where no treatment was provided.

What causes illness?
Pathogens of concern in recreational environments









How is water quality managed? Ensuring safety

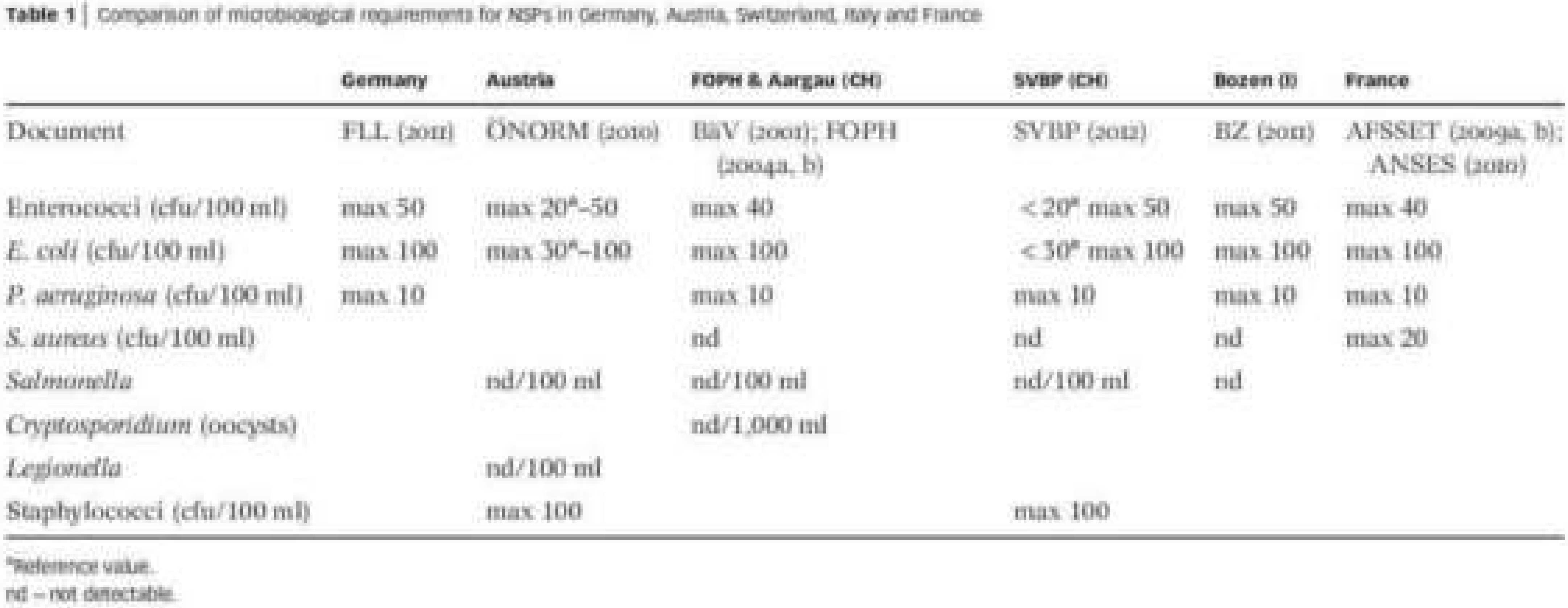


Table 1 | Comparison of microbiological requirements for NSPs in Germany, Austria, Switzerland, Italy and France

	Germany	**Austria**	**FOPH & Aargau (CH)**	**SVBP (CH)**	**Bozen (I)**	**France**
Document	FLL (2011)	ÖNORM (2010)	BäV (2001); FOPH (2004a, b)	SVBP (2012)	BZ (2011)	AFSSET (2009a, b); ANSES (2010)
Enterococci (cfu/100 ml)	max 50	max 20[a]–50	max 40	< 20[a] max 50	max 50	max 40
E. coli (cfu/100 ml)	max 100	max 30[a]–100	max 100	< 30[a] max 100	max 100	max 100
P. aeruginosa (cfu/100 ml)	max 10		max 10	max 10	max 10	max 10
S. aureus (cfu/100 ml)			nd	nd	nd	max 20
Salmonella		nd/100 ml	nd/100 ml	nd/100 ml	nd	
Cryptosporidium (oocysts)			nd/1,000 ml			
Legionella		nd/100 ml				
Staphylococci (cfu/100 ml)		max 100		max 100		

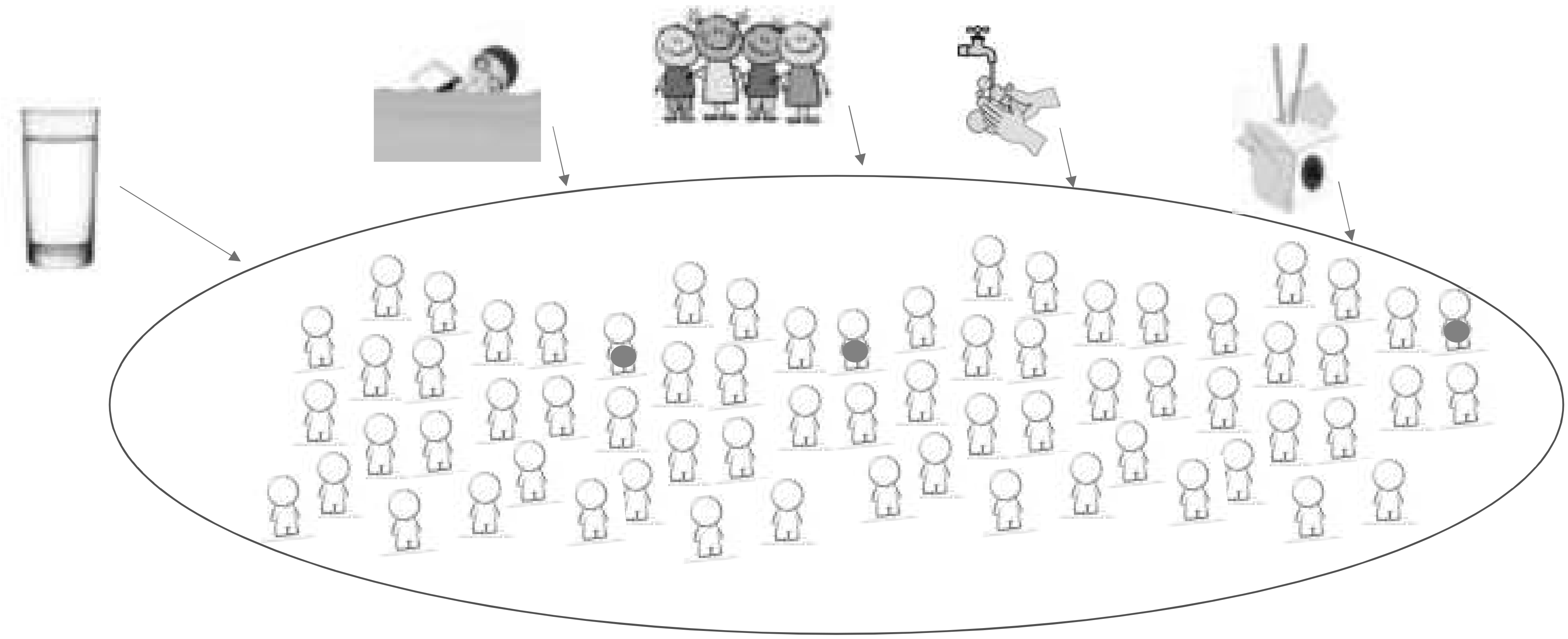
[a] Reference value.

nd – not detectable.

Giampaoli, Saverio, Nathalie Garrec, Gérard Donzé, Federica Valeriani, Lothar Erdinger, and Vincenzo Romano Spica. "Regulations concerning natural swimming ponds in Europe: Considerations on public health issues." *Journal of Water and Health* 12, no. 3 (2014): 564-572.

Why are we interested in microbial risk?

- Ensuring that water management practises are safe



What is a risk based approach to managing water safety?

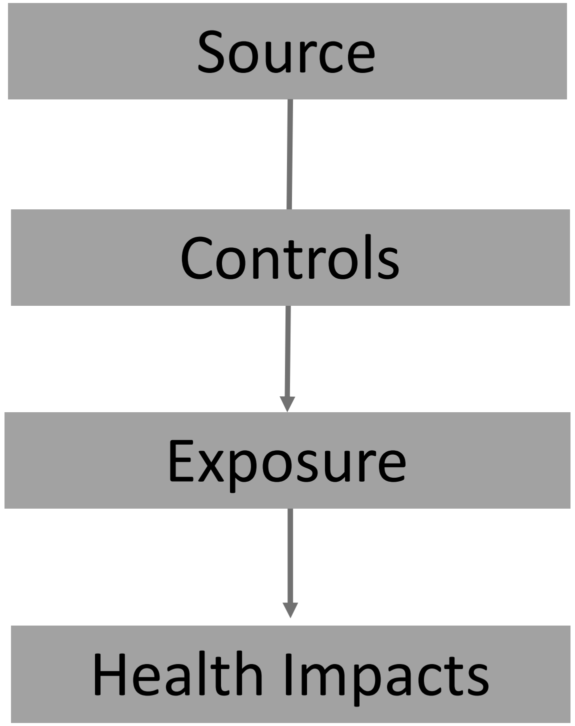
What is risk?

Likelihood of adverse affect, injury or loss

For a given scenario

1. Likelihood (probability of occurrence)
2. Consequence (measure of outcome)
   - Probability of infection/illness
   - Predicted number of cases of illness
   - Change in disease burden

What is a risk based approach to managing water safety?



- Which pathogens are of concerns?
- What are the sources of pathogens to the water?

- What opportunities are there for control?

- What are the exposure pathways?
- What is the magnitude of exposure?

- What are the likely health outcomes?
- Is this acceptable?

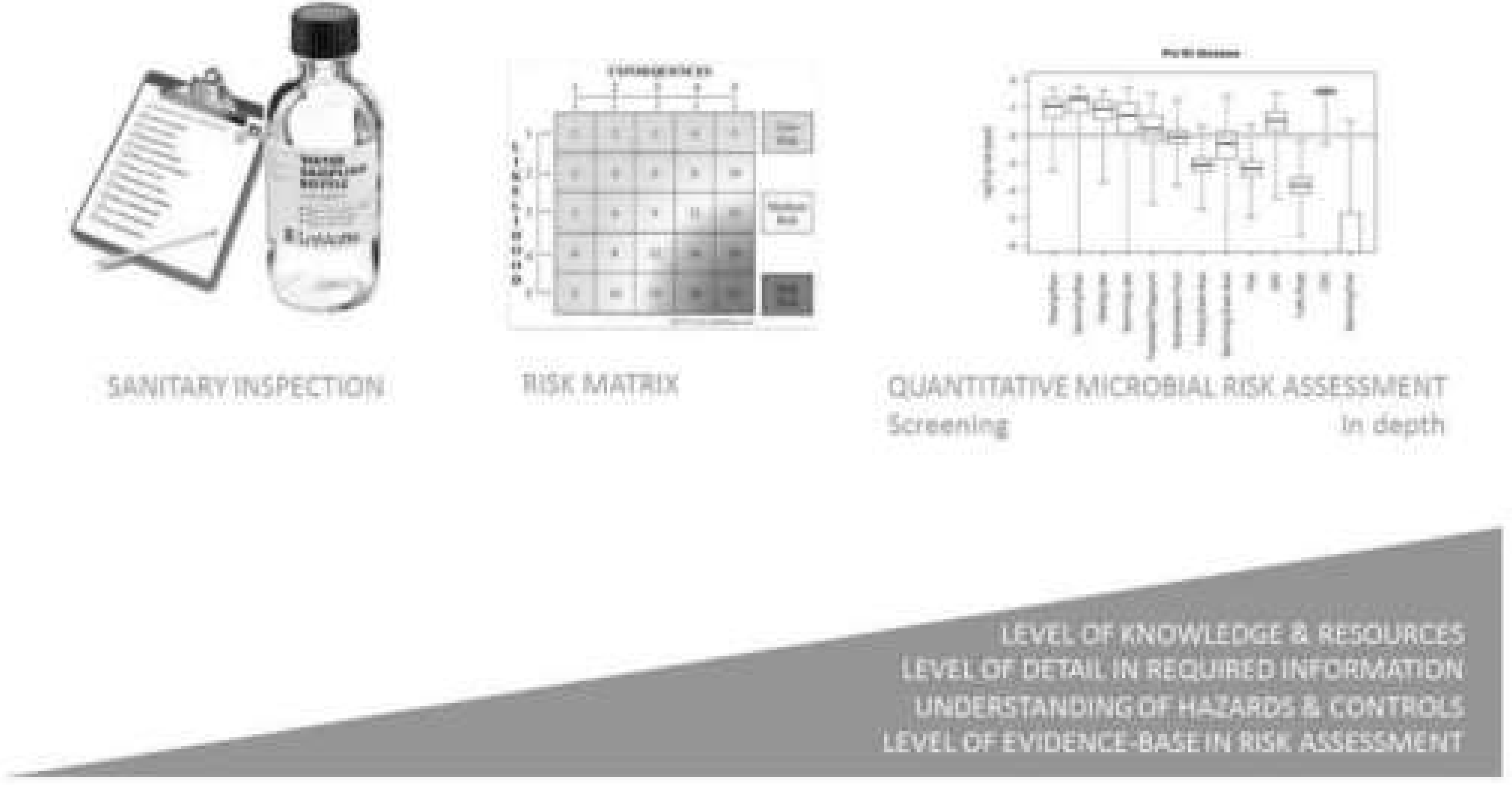
QMRA for Water Safety Management (WHO,2016)

Source

Controls

Exposure

Health impacts



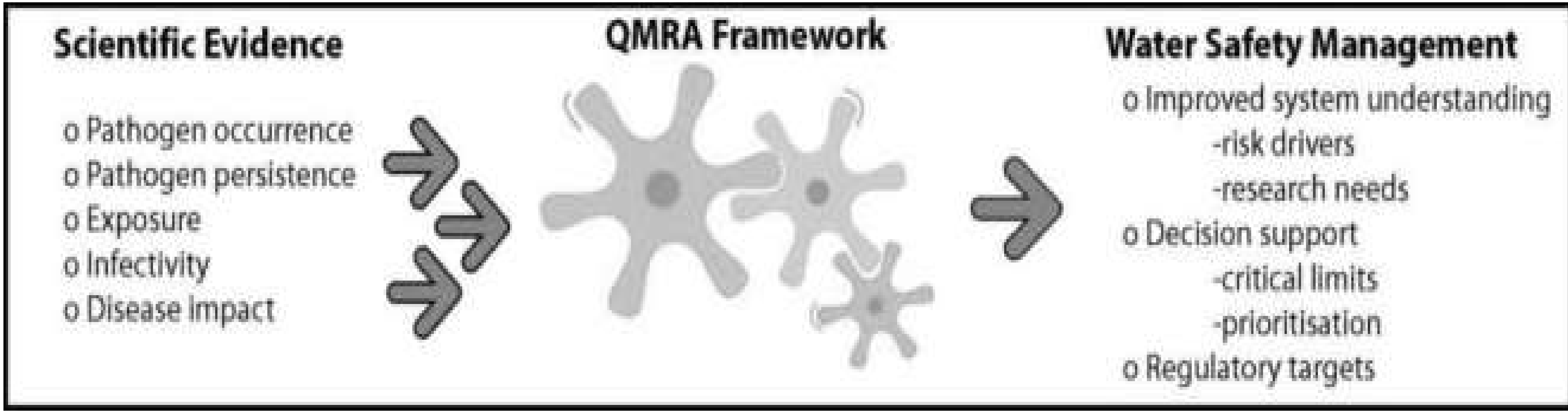
QMRA for Water Safety Management (WHO,2016)

Source

Controls

Exposure

Health impacts



Scientific Evidence

- o Pathogen occurrence
- o Pathogen persistence
- o Exposure
- o Infectivity
- o Disease Impact

QMRA Framework

Water Safety Management

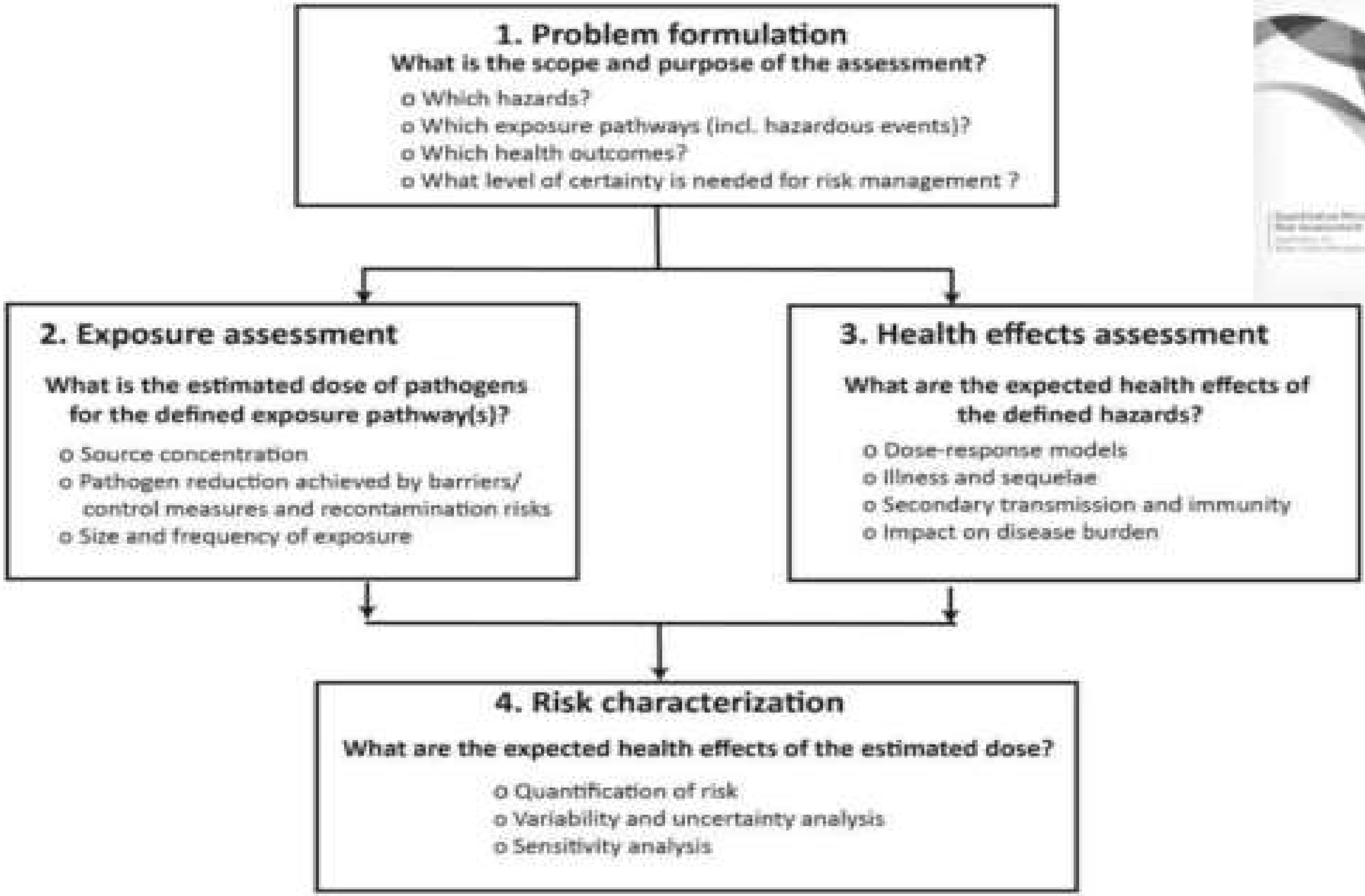
- o Improved system understanding
  - -risk drivers
  - -research needs
- o Decision support
  - -critical limits
  - -prioritisation
- o Regulatory targets

Source

Controls

Exposure

Health impacts



1. Problem formulation

What is the scope and purpose of the assessment?

- Which hazards?
- Which exposure pathways (incl. hazardous events)?
- Which health outcomes?
- What level of certainty is needed for risk management ?

2. Exposure assessment

What is the estimated dose of pathogens for the defined exposure pathway(s)?

- Source concentration
- Pathogen reduction achieved by barriers/ control measures and recontamination risks
- Size and frequency of exposure

3. Health effects assessment

What are the expected health effects of the defined hazards?

- Dose-response models
- Illness and sequelae
- Secondary transmission and immunity
- Impact on disease burden

4. Risk characterization

What are the expected health effects of the estimated dose?

- Quantification of risk
- Variability and uncertainty analysis
- Sensitivity analysis

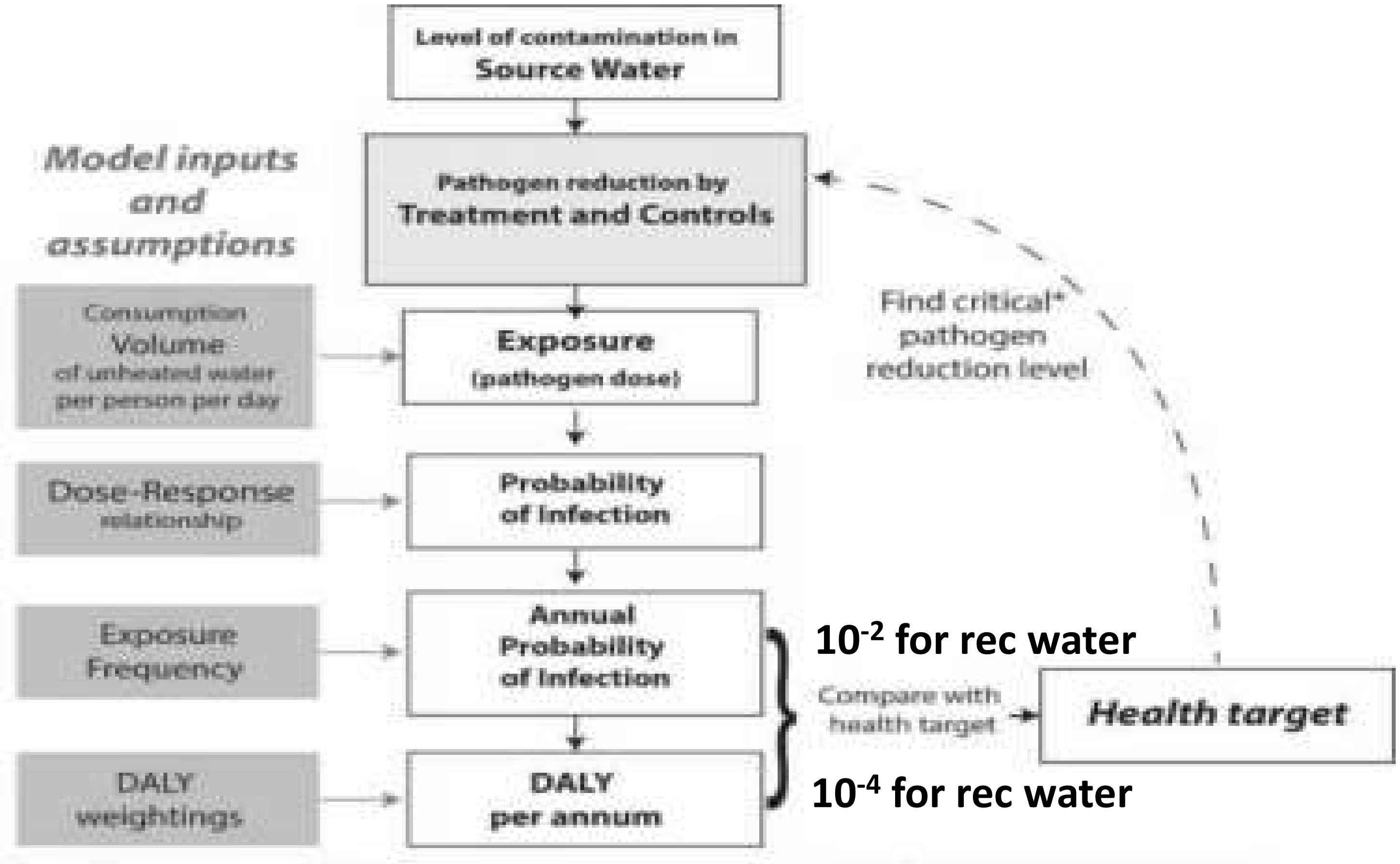
Source

Controls

Exposure

Health
impacts

QMRA for Water Safety Management (WHO,2016)



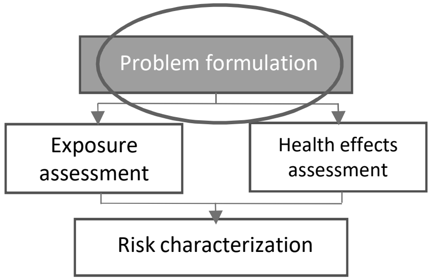
10^{-2} for rec water

10^{-4} for rec water

*The critical pathogen reduction level is the Log_{10} reduction that yields a measure of risk equal to the health target

Petterson & Ashbolt (2016) J Wat Health 4(4): 571-589
WHO (2016) *Quantitative Microbial Risk Assessment, Geneva*

Define the purpose and the scope of the investigation



Fit-for-purpose

Undertake the most simple assessment necessary to achieve the desired outcome

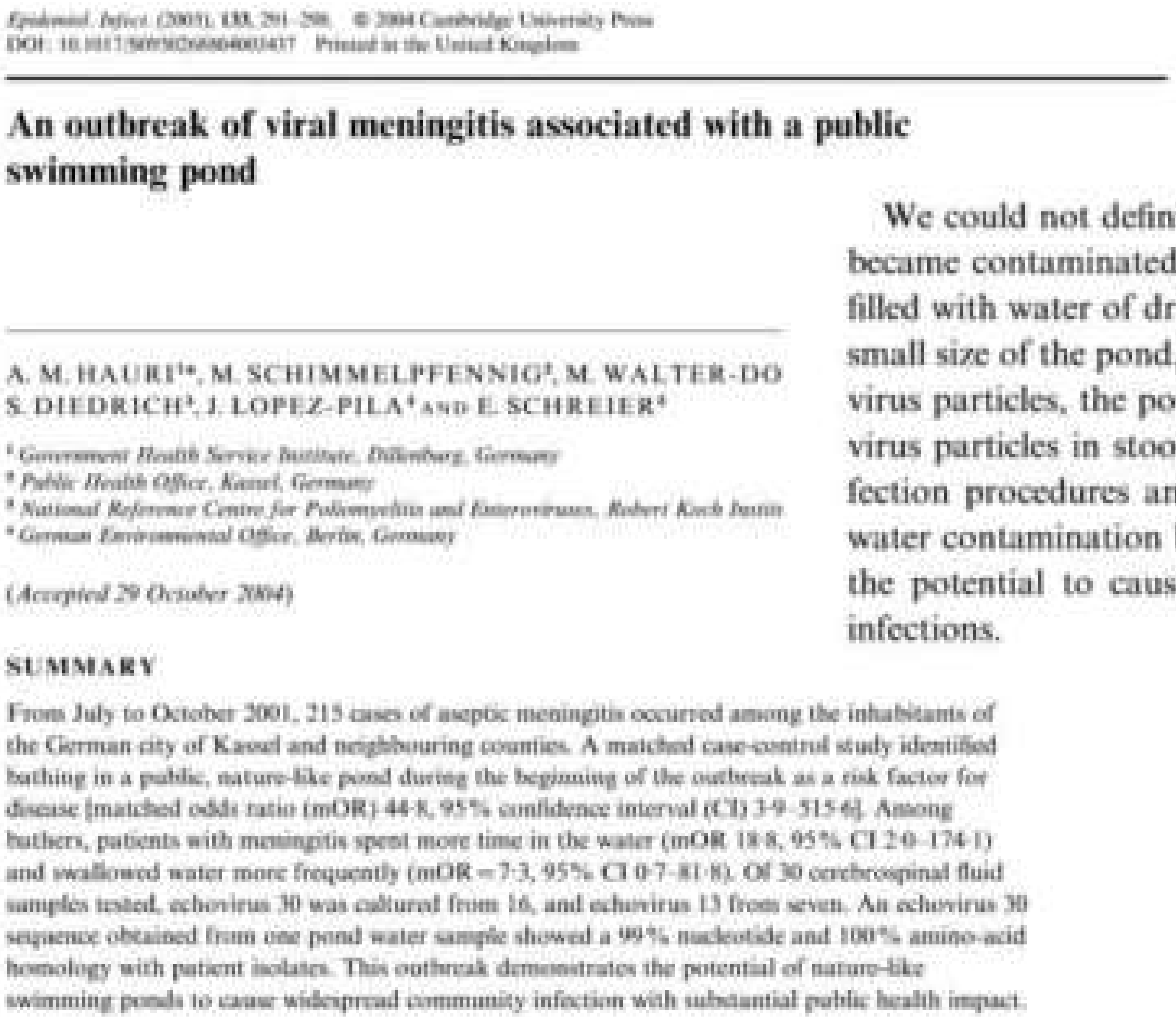
Level of QMRA	Characteristics
Screening	• Provides a broad overview • Can highlight or eliminate concerns • Provides a crude understanding of drivers of risk • Usually relies on worst case point estimates
Advanced	• Greater detail on possible health risks including drivers • Incorporation of additional and site specific data • May be point estimates or limited stochastic analysis
In-depth	• Provides a comprehensive understanding of health risks • Detailed investigation of datasets including incorporation of variability • Usually stochastic estimates of risk.

Source

Controls

Exposure

Health
impacts



Epidemiol. Infect. (2005), 133, 291–298. © 2004 Cambridge University Press
DOI: 10.1017/S0950268804003437 Printed in the United Kingdom

An outbreak of viral meningitis associated with a public swimming pond

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[4] *German Environmental Office, Berlin, Germany*

(*Accepted 29 October 2004*)

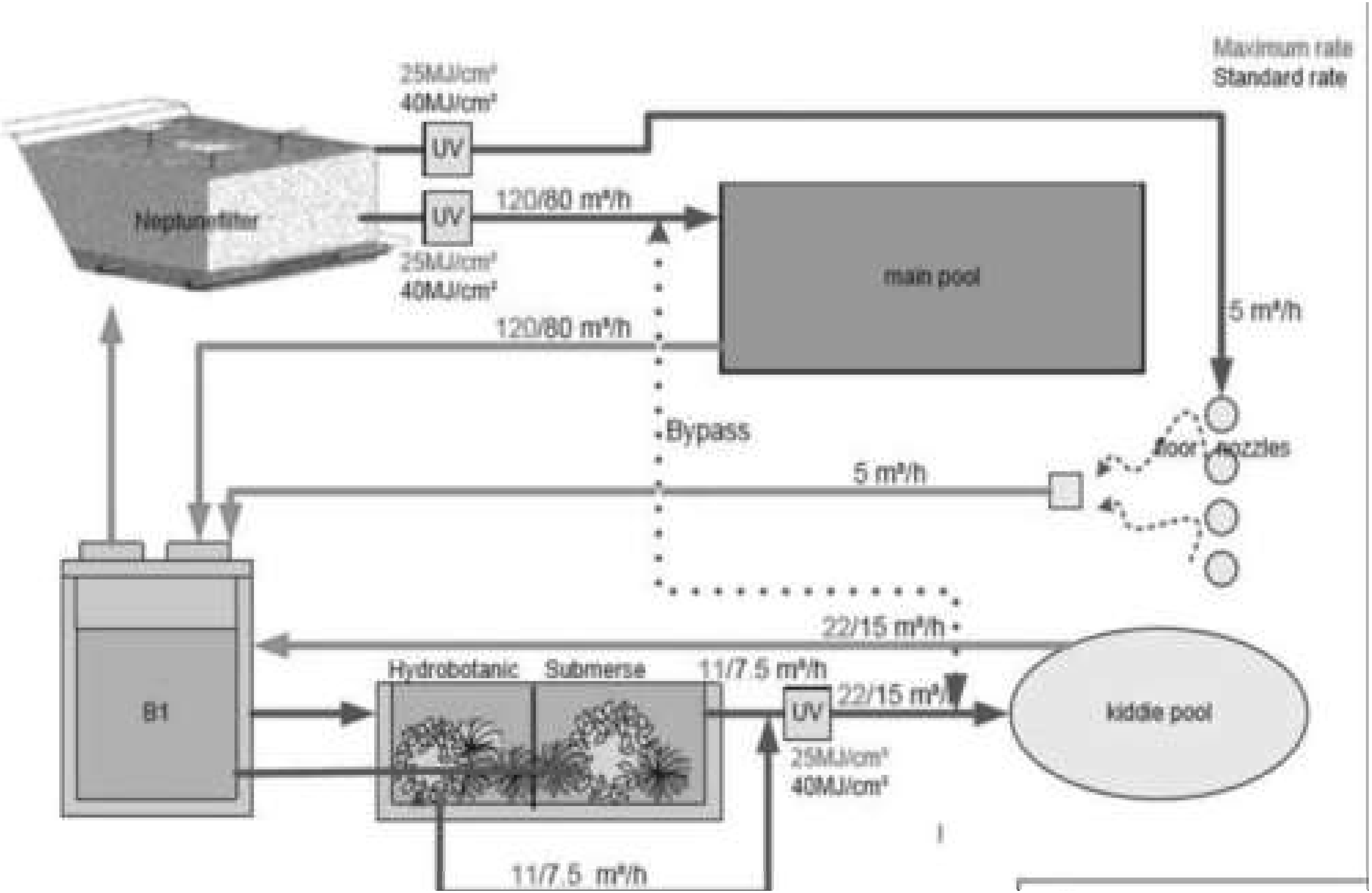
SUMMARY

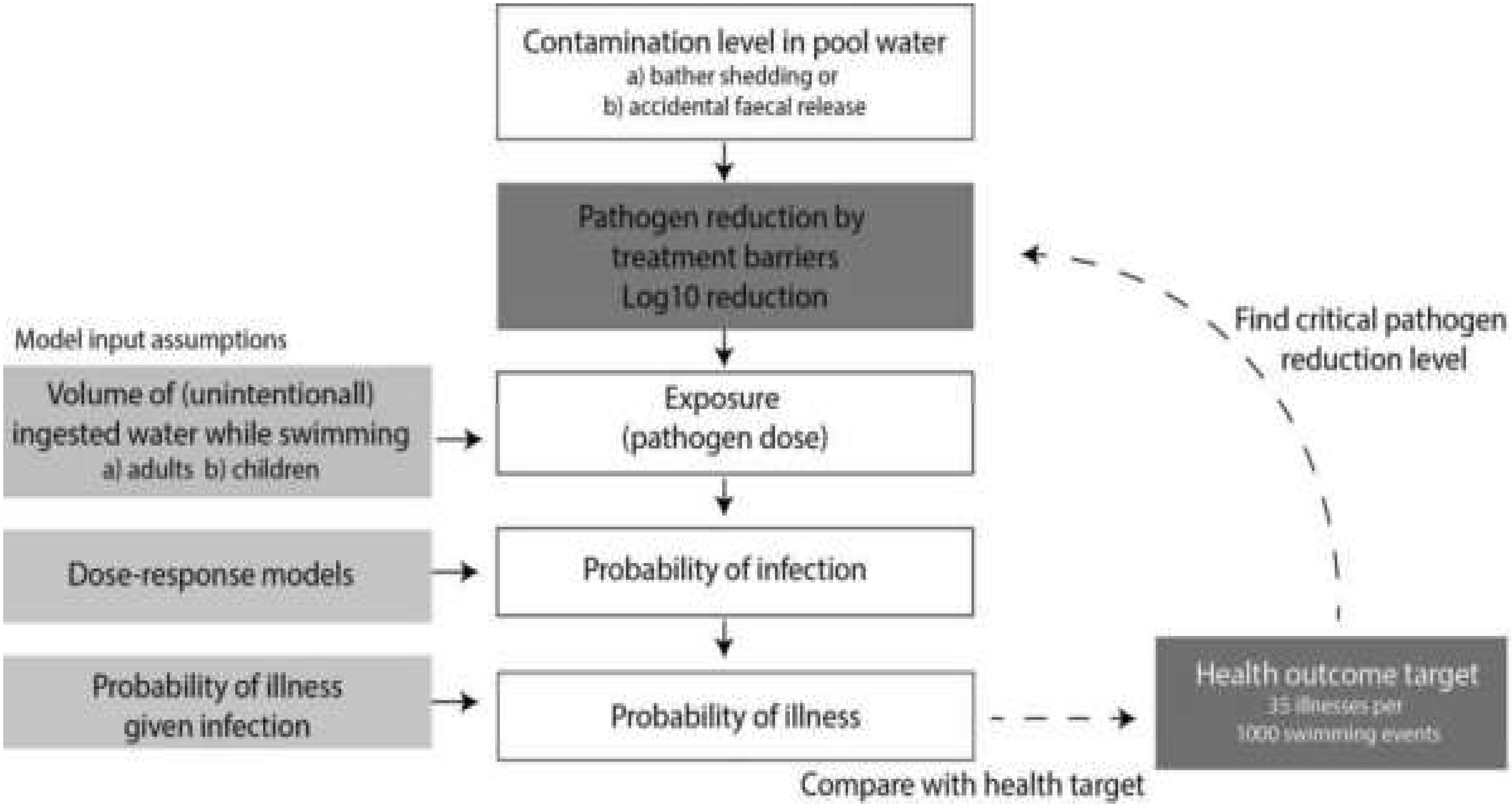
From July to October 2001, 215 cases of aseptic meningitis occurred among the inhabitants of the German city of Kassel and neighbouring counties. A matched case-control study identified bathing in a public, nature-like pond during the beginning of the outbreak as a risk factor for disease [matched odds ratio (mOR) 44·8, 95% confidence interval (CI) 3·9–515·6]. Among bathers, patients with meningitis spent more time in the water (mOR 18·8, 95% CI 2·0–174·1) and swallowed water more frequently (mOR = 7·3, 95% CI 0·7–81·8). Of 30 cerebrospinal fluid samples tested, echovirus 30 was cultured from 16, and echovirus 13 from seven. An echovirus 30 sequence obtained from one pond water sample showed a 99% nucleotide and 100% amino-acid homology with patient isolates. This outbreak demonstrates the potential of nature-like swimming ponds to cause widespread community infection with substantial public health impact.

We could not definitively determine how the pond became contaminated. Bathing ponds have to be refilled with water of drinking-water quality. Given the small size of the pond, the low infective dose of ⩽100 virus particles, the potentially high concentrations of virus particles in stool, the absence of efficient disinfection procedures and the high number of visitors, water contamination by faeces of a single person has the potential to cause a high number of echovirus infections.

Application of QMRA Boden Park NSP, Edmonton, Canada

- **Assessing safety for normal bathing conditions**
- **Assessing safety during accidental faecal release events**
- **Spiking trials of treatment barriers**


Maximum rate
Standard rate
25MJ/cm²
40MJ/cm²
UV
UV
Neptun-filter
120/80 m³/h
25MJ/cm²
40MJ/cm²
main pool
120/80 m³/h
5 m³/h
Bypass
floor nozzles
5 m³/h
22/15 m³/h
Hydrobotanic
Submerse
11/7.5 m³/h
B1
UV
22/15 m³/h
kiddie pool
25MJ/cm²
40MJ/cm²
11/7.5 m³/h


Contamination level in pool water
a) bather shedding or
b) accidental faecal release
Pathogen reduction by treatment barriers Log10 reduction
Model input assumptions
Volume of (unintentionall) ingested water while swimming
a) adults b) children
Exposure (pathogen dose)
Dose-response models
Probability of infection
Probability of illness given infection
Probability of illness
Find critical pathogen reduction level
Health outcome target
35 illnesses per 1000 swimming events
Compare with health target

Bather shedding

Table 1 Amount of faecal material (grams) added to water during contact (reproduced from (Gerba 2000))

Child	0.01-10
Adult	0.1-0.0001
Mean*	0.14

*Average concentration of fecal coliforms shed, for all age groups, during bathing reported by Rose et al. (Rose et al. 1991) was 2.27 × 10^6 and the average fecal coliform concentration per gram of feces is $10^{7.2}$ (Faechem et al. 1983).

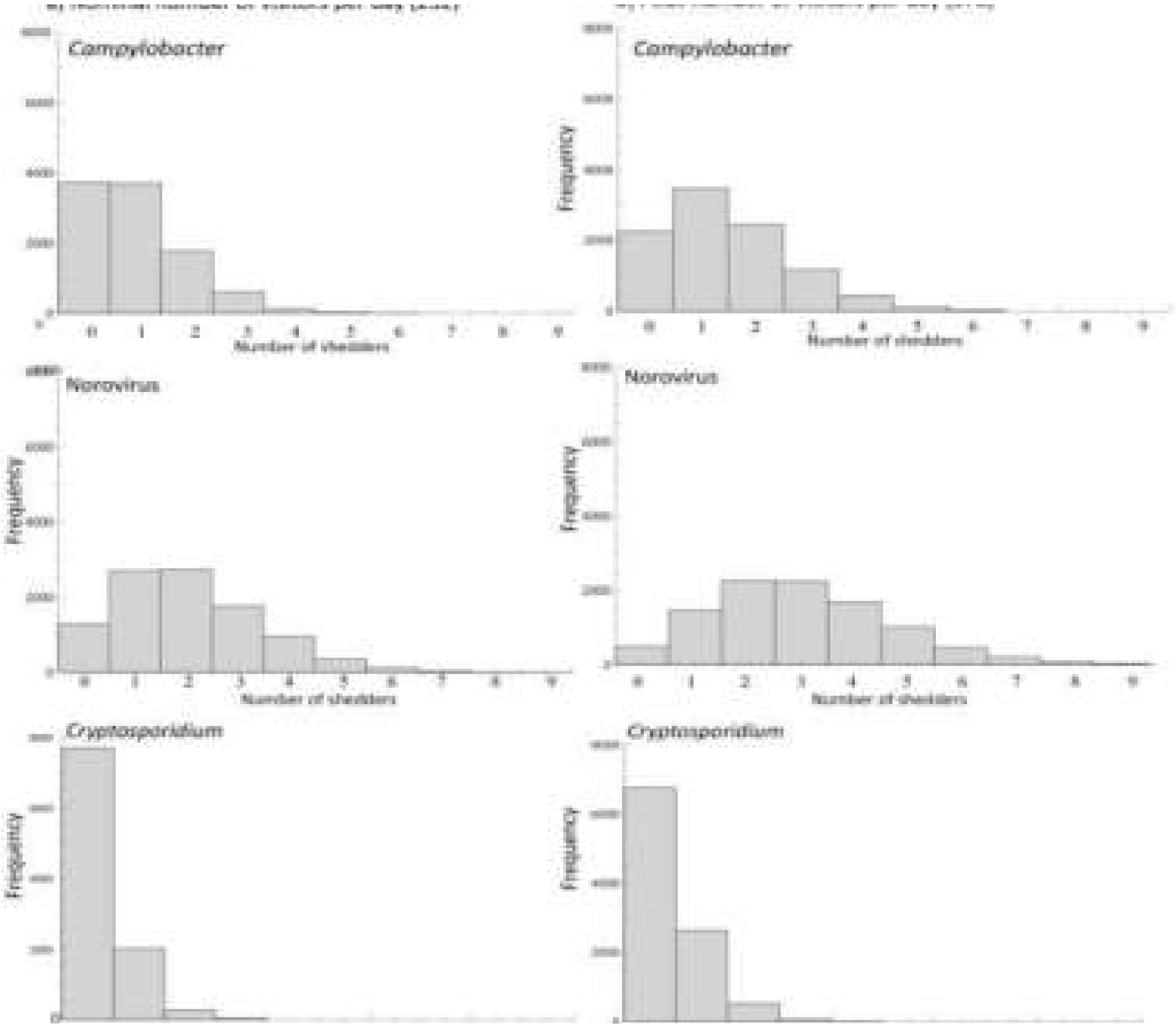
	Campylobacter	Norovirus	*Cryptosporidium*
Reported cases by week*	40	20	15
Under reporting factor	27.2 (Thomas, Murray et al. 2013)	288 (Tam, Rodrigues et al. 2012)	48.5 (Thomas, Murray et al. 2013)
Mean duration of excretion (days)	21 (Havelaar, van Pelt et al. 2009)	28.5 (Tu, Bull et al. 2008)	30 (Stehr-Green, McCaig et al. 1987)
Asymptomatic infection rate	0.8 (Black, Levine et al. 1988)	0.3 (Teunis, Moe et al. 2008)	0.3 (USEPA 2006)
Calculated Point Prevalence (%)	0.39	0.80	0.11

Source

Controls

Exposure

Health impacts

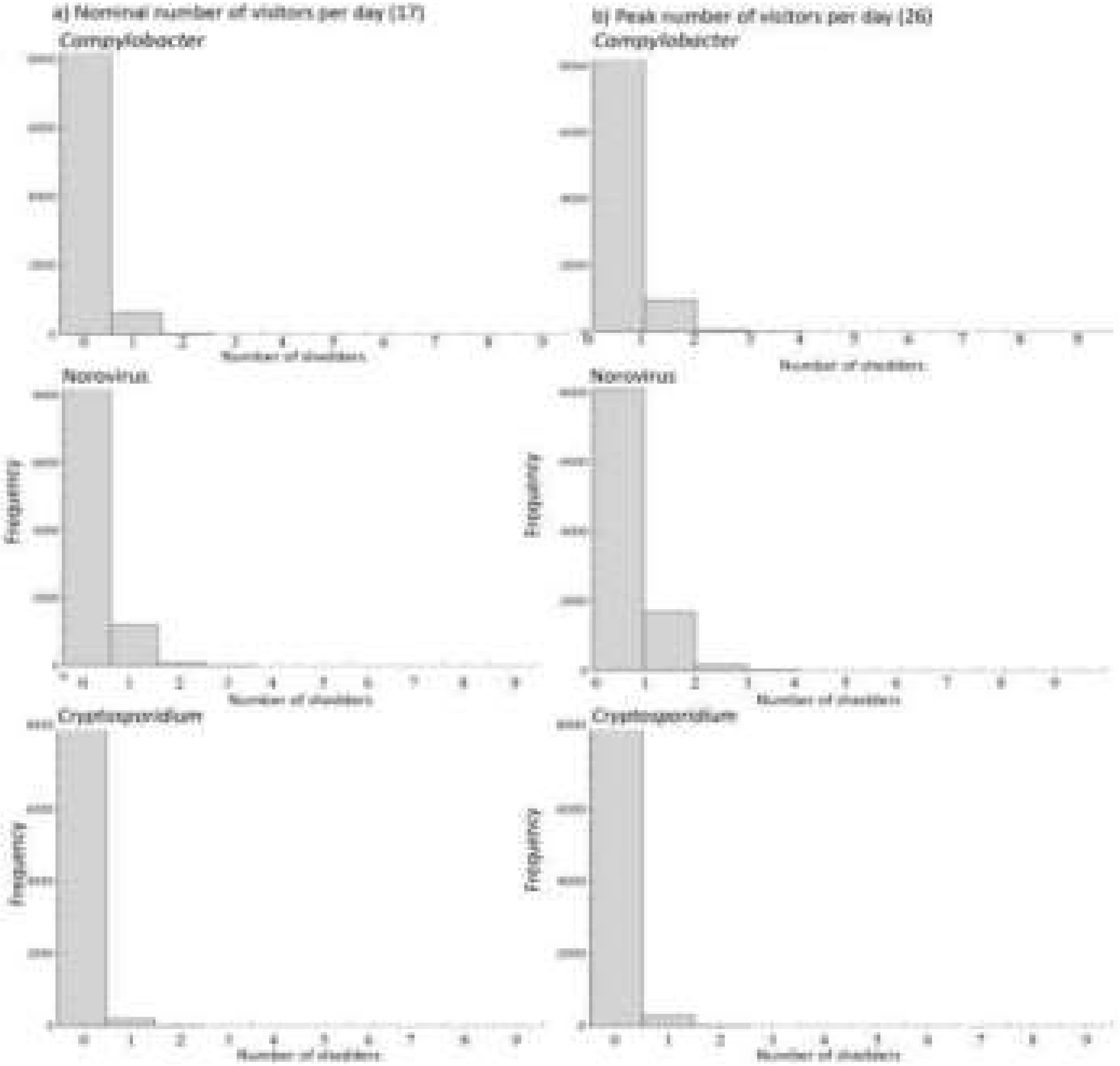


Source

Controls

Exposure

Health impacts



Source

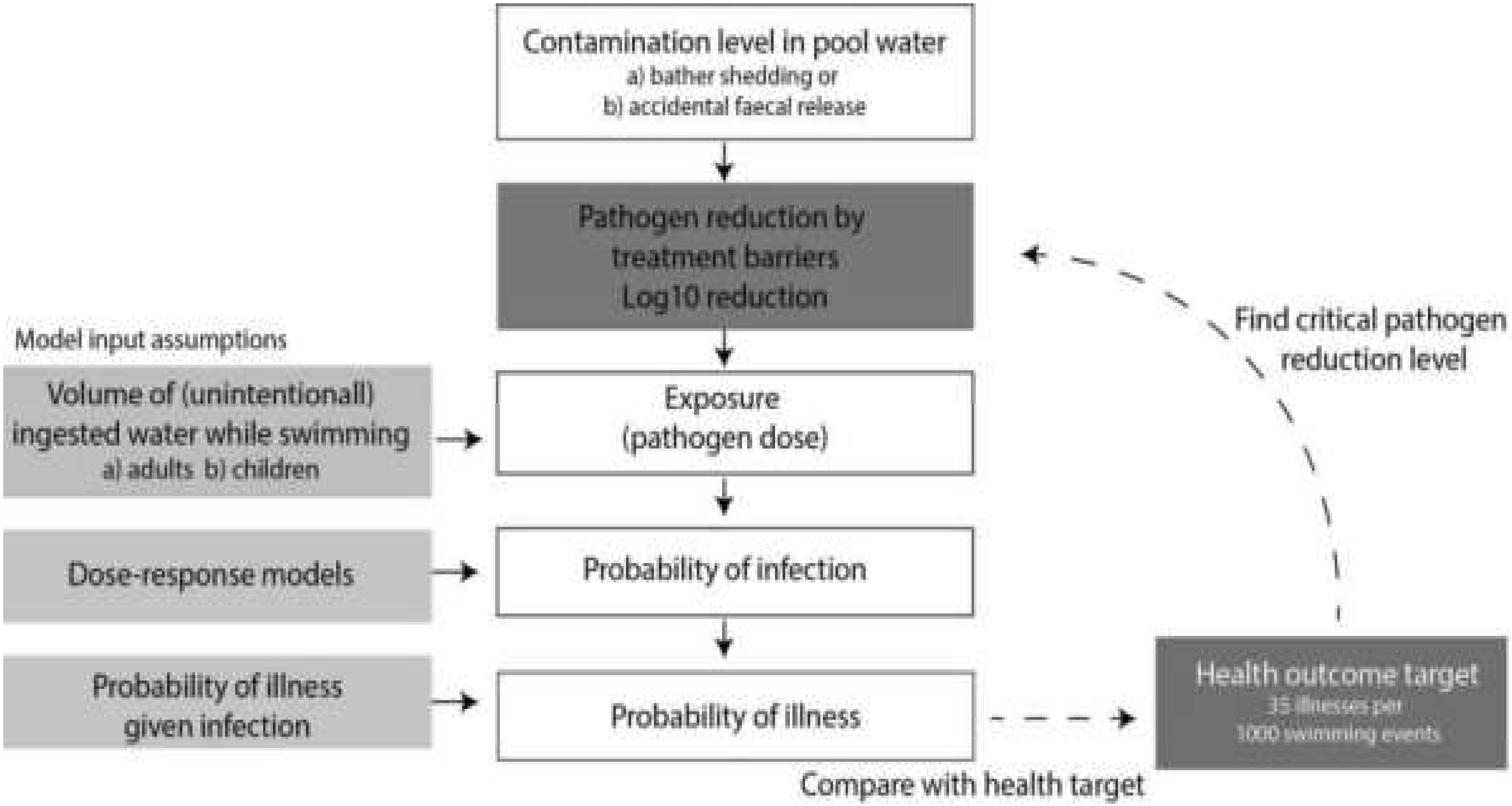
Controls

Exposure

Health impacts

QMRA estimates of reference pathogen concentration

	Estimated Reference Pathogen concentration (pathogens.L^{-1})		
to meet 32 illness/1,000 swims	Percentile		
MAIN POOL	50	75	95
Campylobacter			
Nominal bathers	0.067	6.0	65
Peak bathers	1.1	15	93
Norovirus			
Nominal bathers	230	1,300	8,000
Peak bathers	620	2,500	11,000
Giardia			
Nominal bathers	0	0	4.11
Peak bathers	0	0.34	5.73
Cryptosporidium			
Nominal bathers	0	0	0.43
Peak bathers	0	0.038	0.63
KIDDIE POOL			
Campylobacter			
Nominal bathers	0	0	0.27
Peak bathers	0	0	9.7
Norovirus			
Nominal bathers	0	0	2,300
Peak bathers	0	0	6,100



Contamination level in pool water
a) bather shedding or
b) accidental faecal release

Pathogen reduction by treatment barriers Log10 reduction

Exposure (pathogen dose)

Probability of infection

Probability of illness

Model input assumptions

Volume of (unintentionall) ingested water while swimming
a) adults b) children

Dose-response models

Probability of illness given infection

Find critical pathogen reduction level

Health outcome target
35 illnesses per
1000 swimming events

Compare with health target

U.S. EPA Criteria for Recreational Waters

- Based on a suite of epidemiology studies that concluded*:

  32 illnesses per 1,000 swimming events is the background risk level

  equates to median of < 30 enterococci per 100 mL or by qPCR single sample value of < 1,280 CCE/100 mL (or 110 CFU enterococci per 100 mL)

  Also may equate to 4,200 copies of HF183 sewage marker by qPCR
- For different situation to sewage contamination of recreational waters EPA recommends undertaking a quantitative microbial risk assessment (QMRA)
  - Using reference pathogens to address enteric viruses, bacteria & parasitic protozoa

***US-EPA.** 2012. *Recreational Water Quality Criteria*. EPA 820-F-12-058. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Assumed ingestion & ref pathogen dose-response models

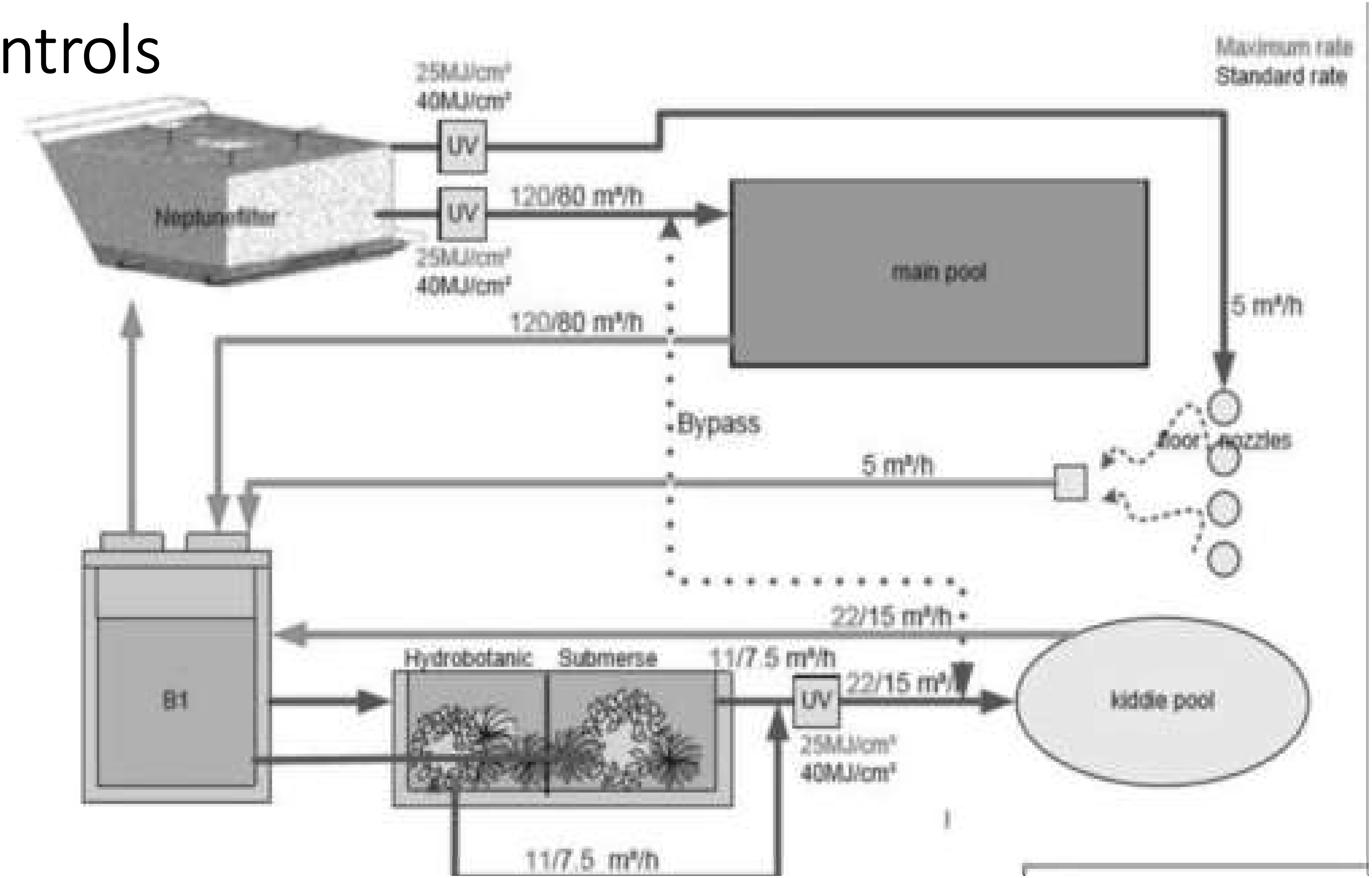
	Adult	Child
Accidental ingestion	16 mL (Dufour)	37 mL (Dufour)
Faeces released	0.0001 – 0.1 g (Gerba 2000)	0.01 – 10 g (Gerba 2000)
Swimmers per day	x	y

	Campylobacter	*Norovirus*	*Cryptosporidium*
Dose-response model: Exact Beta-Poisson parameters for infection	α = 0.024; β = 0.011 (Teunis, Van Den Brandhof et al. 2005)	α = 0.063; β = 0.032 (Messner, Berger et al. 2014)	α = 0.115; β = 0.176 (Teunis, Van Den Brandhof et al. 2005)
Probability of illness given infection	0.2 (Black, Levine et al. 1988)	0.7 (Teunie et al. 2008)	0.7 (U.S. EPA 2006)
Critical dose (# organisms for <32 illness/1,000): Adults (children)	18.4 (7.9)	4.9 (2.1)	8.4 (3.6)

QMRA estimates for Pathogens & LRV needed

	Estimated Reference Pathogen concentration (pathogens.L^{-1})			**Required Log_{10} reduction to achieve safe water quality***					
				Adults			Children		
to meet 32 illness/1,000 swims	Percentile			Percentile			Percentile		
MAIN POOL	50	75	95	50	75	95	50	75	95
Campylobacter									
Nominal bathers	0.067	6.0	65	0	0	0.56	0	0	0.92
Peak bathers	1.1	15	93	0	0	0.70	0	0.26	1.1
Norovirus									
Nominal bathers	230	1,300	8,000	1.7	2.4	3.2	2.0	2.8	3.6
Peak bathers	620	2,500	11,000	2.1	2.7	3.3	2.5	3.1	3.7
Giardia									
Nominal bathers	0	0	4.11	0	0	0	0	0	0
Peak bathers	0	0.34	5.73	0	0	0	0	0	0
Cryptosporidium									
Nominal bathers	0	0	0.43	0	0	0	0	0	0
Peak bathers	0	0.038	0.63	0	0	0	0	0	0
KIDDIE POOL									
Campylobacter									
Nominal bathers	0	0	0.27	0	0	0	0	0	0
Peak bathers	0	0	9.7	0	0	0	0	0	0.15
Norovirus									
Nominal bathers	0	0	2,300	0	0	0	0	0	3.0
Peak bathers	0	0	6,100	0	0	0	0	0	3.4

Controls



Maximum rate
Standard rate
25MJ/cm²
40MJ/cm²
UV
Neptun-filter
UV
120/80 m³/h
25MJ/cm²
40MJ/cm²
main pool
5 m³/h
120/80 m³/h
Bypass
floor nozzles
5 m³/h
22/15 m³/h
Hydrobotanic
Submerse
11/7.5 m³/h
B1
UV
22/15 m³/h
kiddie pool
25MJ/cm²
40MJ/cm²
11/7.5 m³/h

Source

Controls

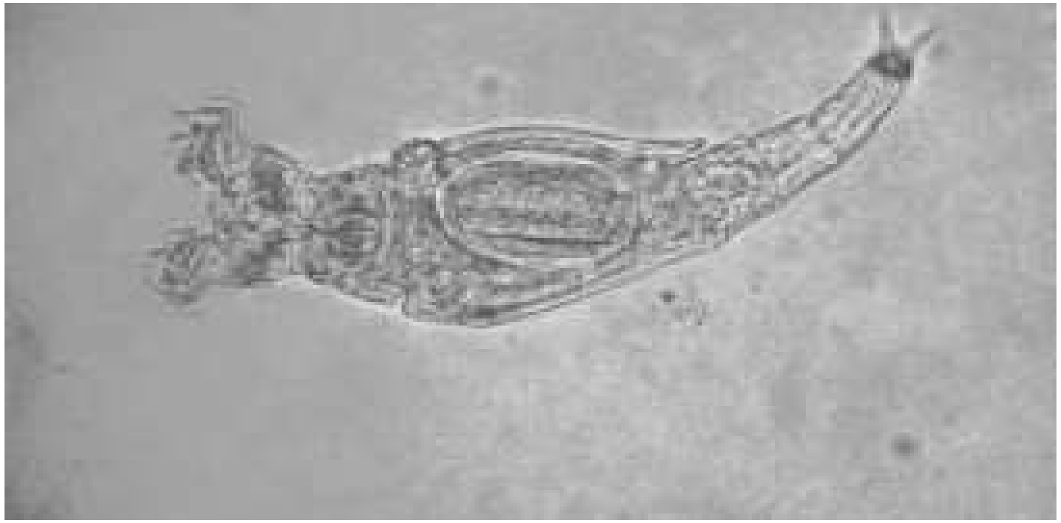
Exposure

Health impacts

Estimated performance of removal barriers

	Best estimate of elimination capacity ($\log_{10}$ reduction) (with plausible ranges applied in Monte Carlo simulation)		
	Bacteria	Viruses	Protozoa
Zooplankton filtering	0	0	0
Neptune Filter	2 (1, 3)	1 (0.5, 2.5)	1.5 (0.2 ,3)
Submerse substrate Filter	1 (0, 2)	0.5 (0, 2)	1 (0.2, 2.5)
Hydro-botanic plant	1 (0, 2)	0.5 (0, 2))	1 (0.2, 2.5)
UV (25 $MJ.cm^{-2}$)	5	2.6	3

Zooplankton filtering



Source

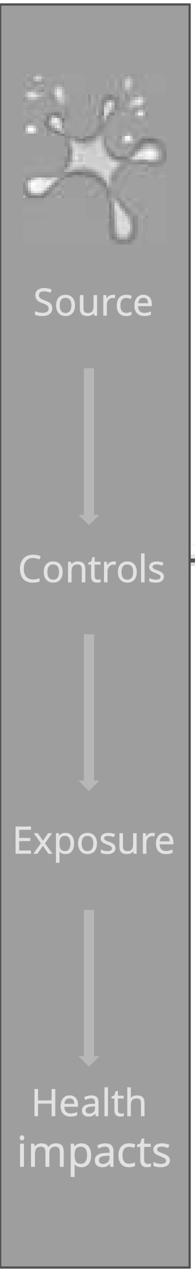
Controls

Exposure

Health impacts

Filtration rate

	Minimum	Maximum	Average
	Fmin	Fmax	Fav
Genus	ml/Ind./d	ml/Ind./d	ml/Ind./d
Ciliata	0.012	0.163	0.0875
Rotatoria	0.007	16.992	8.5
Copepoda	0.048	129.6	64.824
Cladocera	0.096	66.48	33.288

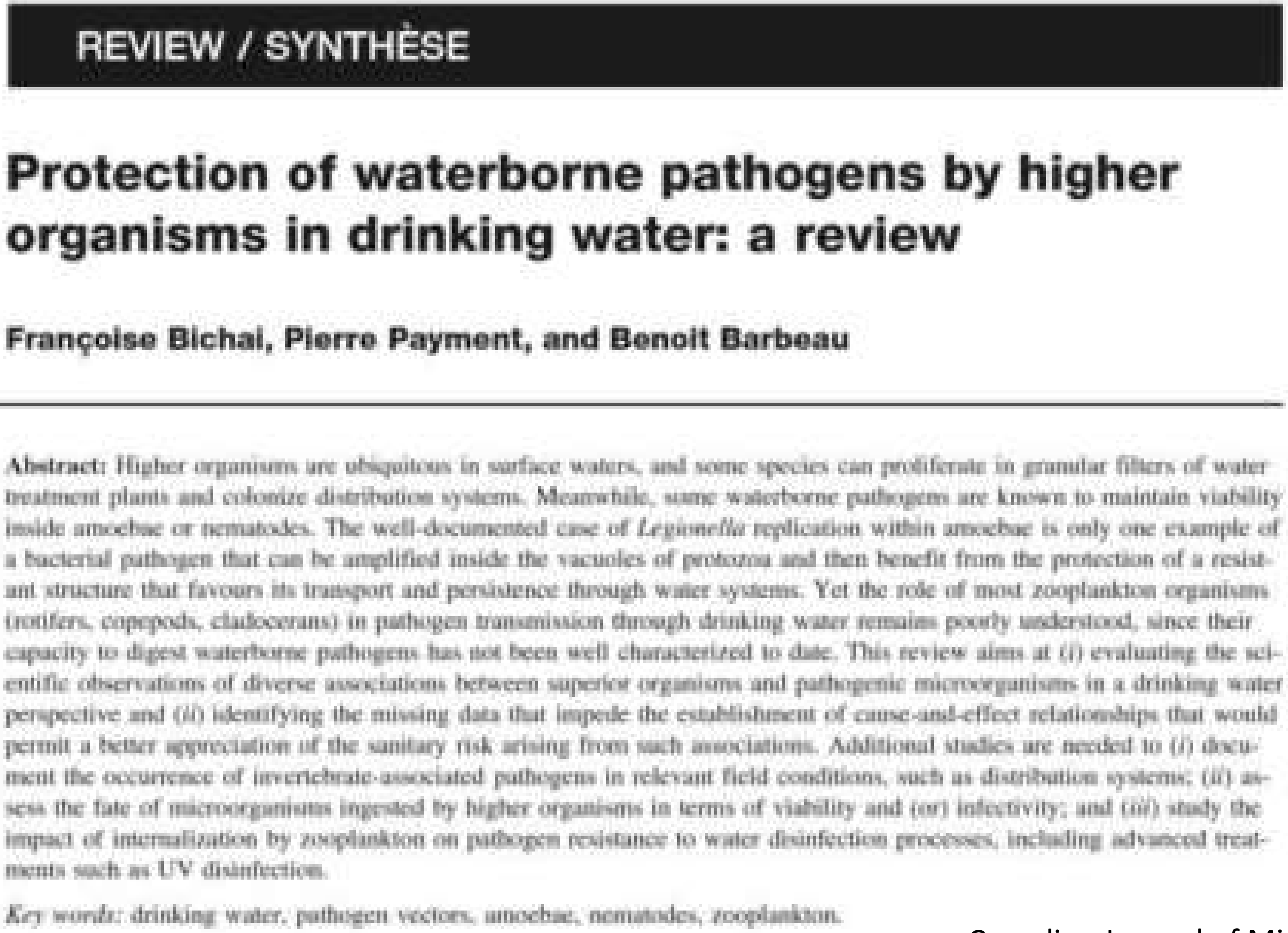


Source

Controls

Exposure

Health impacts



REVIEW / SYNTHÈSE

Protection of waterborne pathogens by higher organisms in drinking water: a review

Françoise Bichai, Pierre Payment, and Benoit Barbeau

Abstract: Higher organisms are ubiquitous in surface waters, and some species can proliferate in granular filters of water treatment plants and colonize distribution systems. Meanwhile, some waterborne pathogens are known to maintain viability inside amoebae or nematodes. The well-documented case of *Legionella* replication within amoebae is only one example of a bacterial pathogen that can be amplified inside the vacuoles of protozoa and then benefit from the protection of a resistant structure that favours its transport and persistence through water systems. Yet the role of most zooplankton organisms (rotifers, copepods, cladocerans) in pathogen transmission through drinking water remains poorly understood, since their capacity to digest waterborne pathogens has not been well characterized to date. This review aims at (*i*) evaluating the scientific observations of diverse associations between superior organisms and pathogenic microorganisms in a drinking water perspective and (*ii*) identifying the missing data that impede the establishment of cause-and-effect relationships that would permit a better appreciation of the sanitary risk arising from such associations. Additional studies are needed to (*i*) document the occurrence of invertebrate-associated pathogens in relevant field conditions, such as distribution systems; (*ii*) assess the fate of microorganisms ingested by higher organisms in terms of viability and (or) infectivity; and (*iii*) study the impact of internalization by zooplankton on pathogen resistance to water disinfection processes, including advanced treatments such as UV disinfection.

Key words: drinking water, pathogen vectors, amoebae, nematodes, zooplankton.

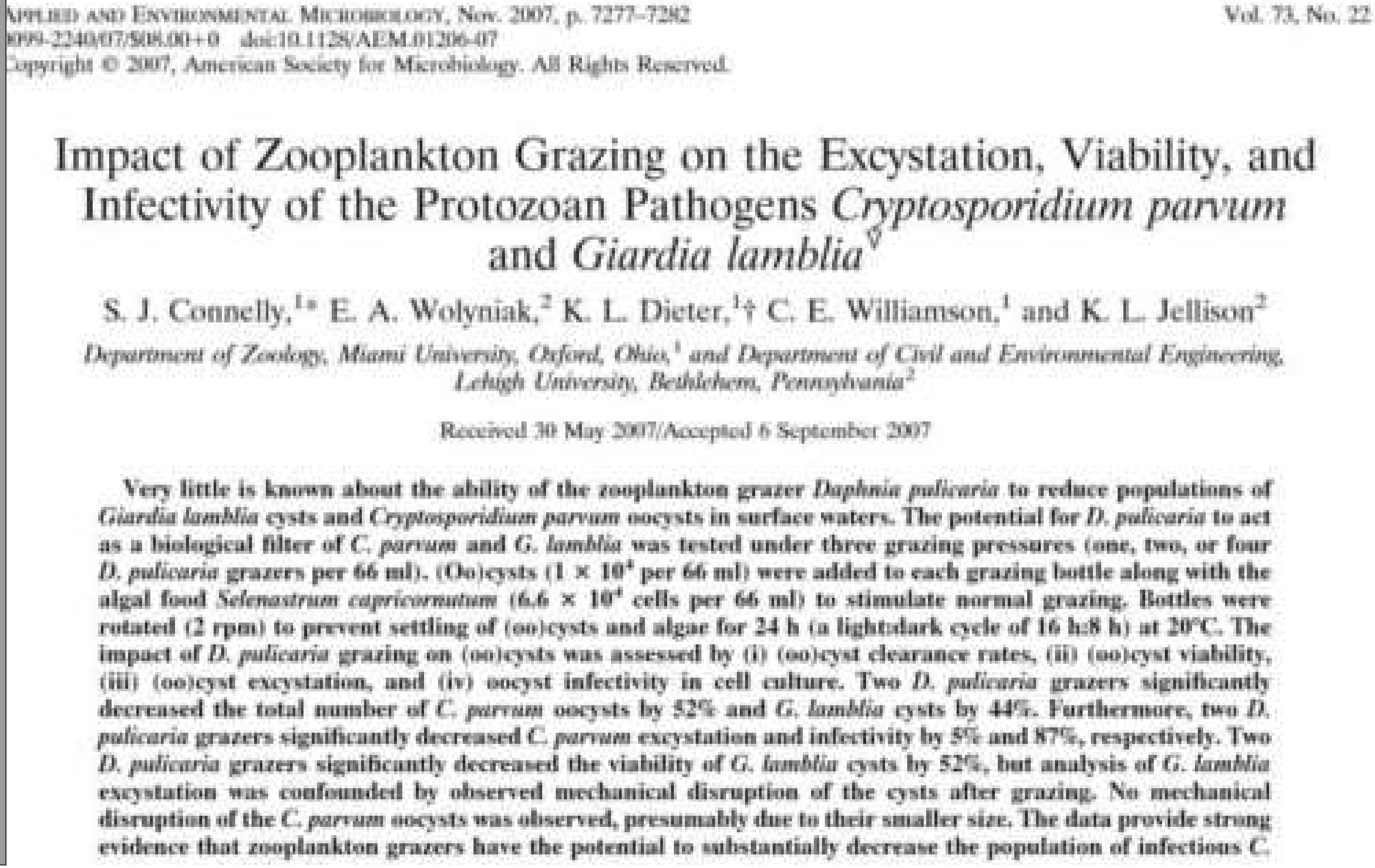
Canadian Journal of Microbiology, 2008

Source

Controls

Exposure

Health impacts



APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Nov. 2007, p. 7277–7282 Vol. 73, No. 22
099-2240/07/$08.00+0 doi:10.1128/AEM.01206-07

Impact of Zooplankton Grazing on the Excystation, Viability, and Infectivity of the Protozoan Pathogens *Cryptosporidium parvum* and *Giardia lamblia*▽

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Received 30 May 2007/Accepted 6 September 2007

Very little is known about the ability of the zooplankton grazer *Daphnia pulicaria* to reduce populations of *Giardia lamblia* cysts and *Cryptosporidium parvum* oocysts in surface waters. The potential for *D. pulicaria* to act as a biological filter of *C. parvum* and *G. lamblia* was tested under three grazing pressures (one, two, or four *D. pulicaria* grazers per 66 ml). (Oo)cysts (1×10^4 per 66 ml) were added to each grazing bottle along with the algal food *Selenastrum capricornutum* (6.6×10^4 cells per 66 ml) to stimulate normal grazing. Bottles were rotated (2 rpm) to prevent settling of (oo)cysts and algae for 24 h (a light:dark cycle of 16 h:8 h) at 20°C. The impact of *D. pulicaria* grazing on (oo)cysts was assessed by (i) (oo)cyst clearance rates, (ii) (oo)cyst viability, (iii) (oo)cyst excystation, and (iv) oocyst infectivity in cell culture. Two *D. pulicaria* grazers significantly decreased the total number of *C. parvum* oocysts by 52% and *G. lamblia* cysts by 44%. Furthermore, two *D. pulicaria* grazers significantly decreased *C. parvum* excystation and infectivity by 5% and 87%, respectively. Two *D. pulicaria* grazers significantly decreased the viability of *G. lamblia* cysts by 52%, but analysis of *G. lamblia* excystation was confounded by observed mechanical disruption of the cysts after grazing. No mechanical disruption of the *C. parvum* oocysts was observed, presumably due to their smaller size. The data provide strong evidence that zooplankton grazers have the potential to substantially decrease the population of infectious *C.*

Source

Controls

Exposure

Health impacts

Estimated performance of removal barriers

	Best estimate of elimination capacity (log$_{10}$ reduction) (with plausible ranges applied in Monte Carlo simulation)		
	Bacteria	Viruses	Protozoa
Zooplankton filtering	0	0	0
Neptune Filter	2 (1, 3)	1 (0.5, 2.5)	1.5 (0.2 ,3)
Submerse substrate Filter	1 (0, 2)	0.5 (0, 2)	1 (0.2, 2.5)
Hydro-botanic plant	1 (0, 2)	0.5 (0, 2)	1 (0.2, 2.5)
UV (25 MJ.cm^{-2})	5	2.6	3

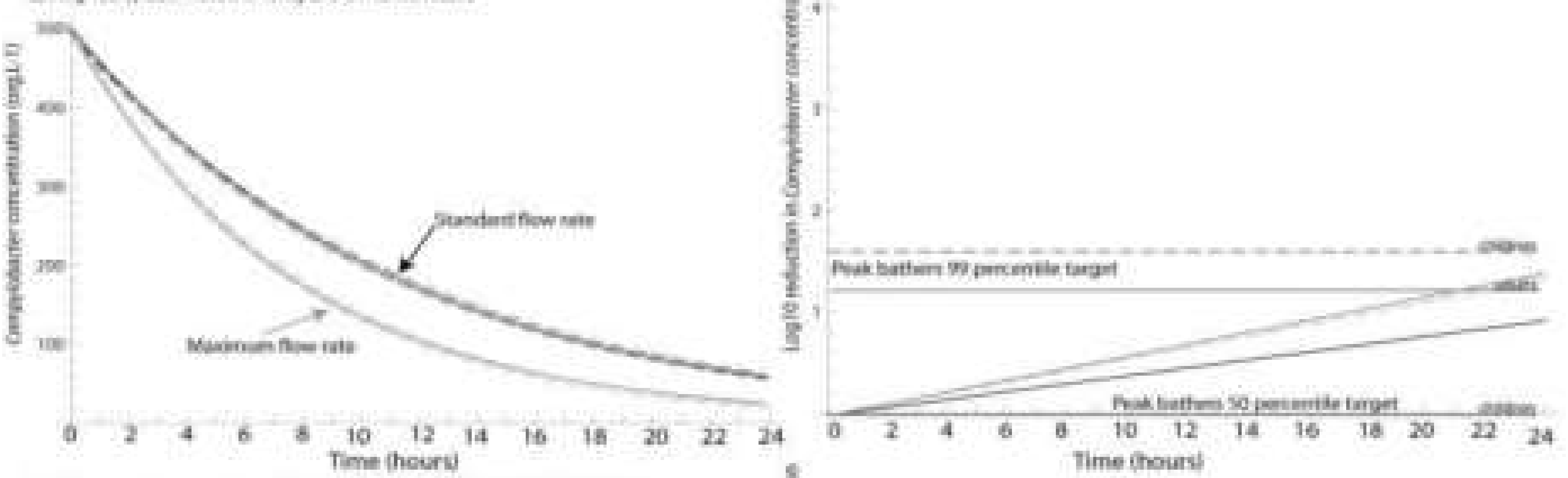
Source

Controls

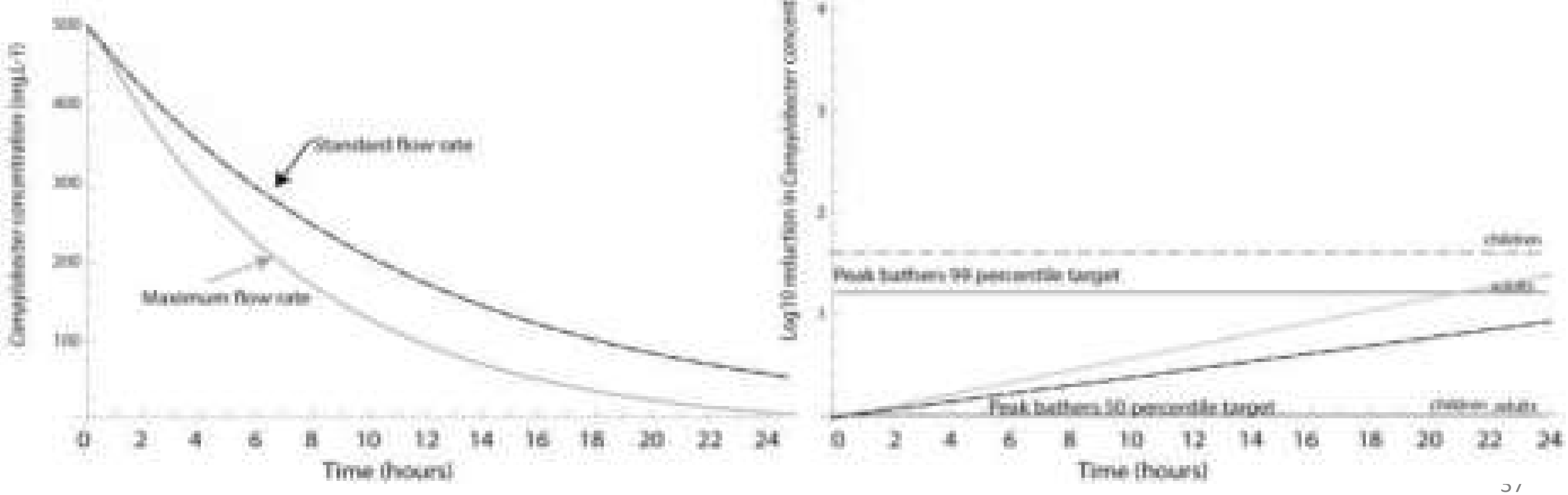
Exposure

Health impacts

a) Neptune, submerse and hydro botanic filters



b) Neptune, submerse, hydro botanic filters and UV DISINFECTION

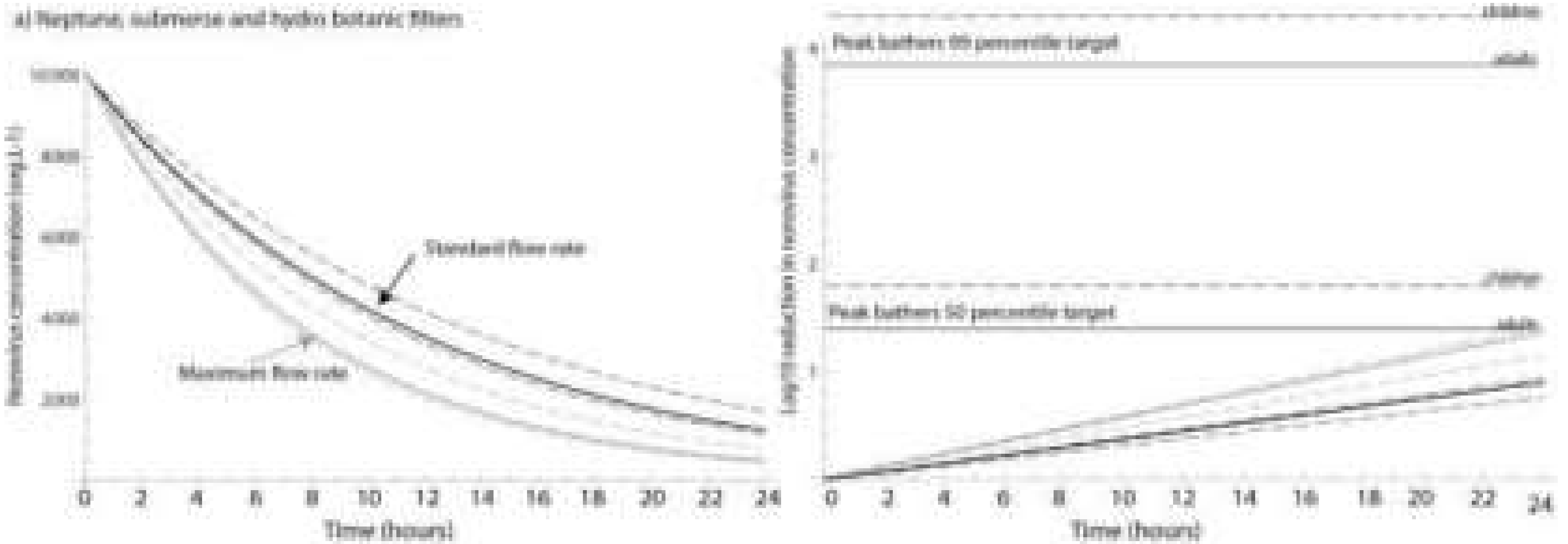


Source

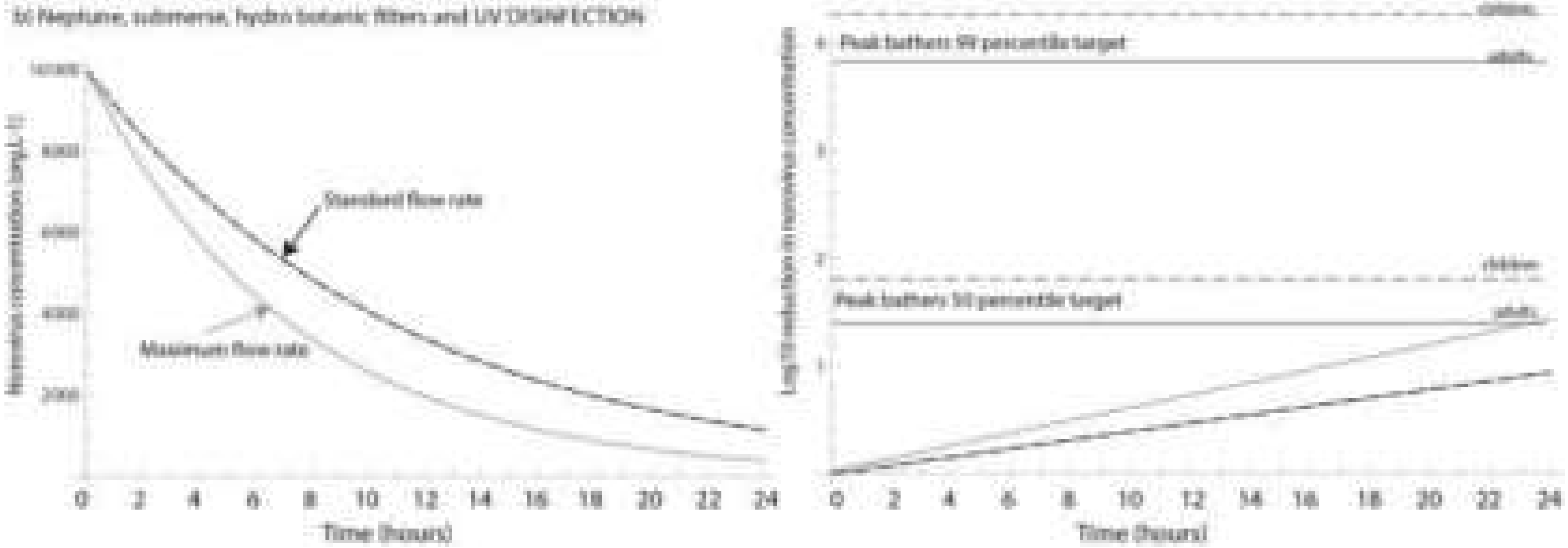
Controls

Exposure

Health impacts



a) Neptune, submerse and hydro botanic filters



b) Neptune, submerse, hydro botanic filters and UV DISINFECTION

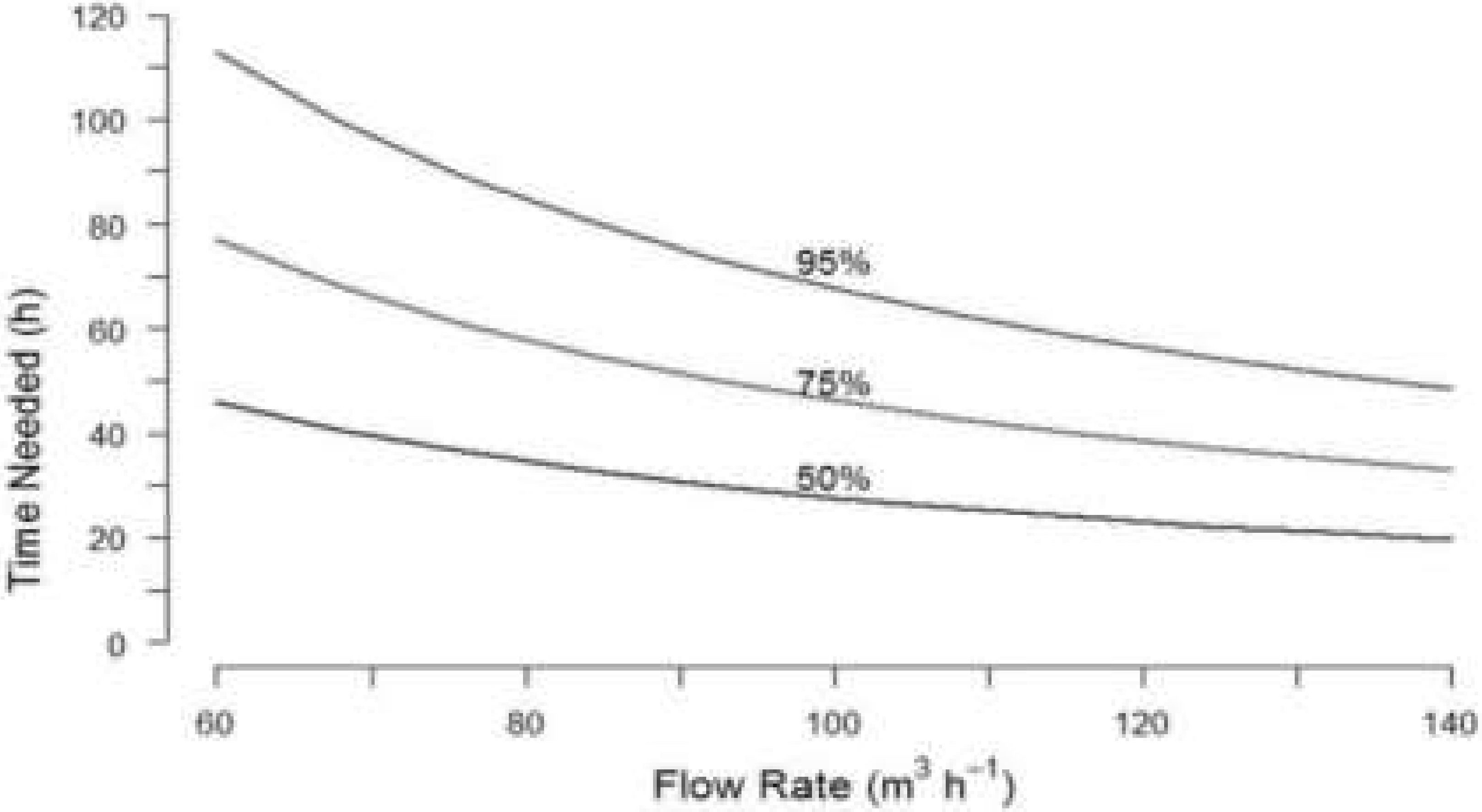
Source

Controls

Exposure

Health impacts

Time to reach Benchmark Risk Level by flow rate



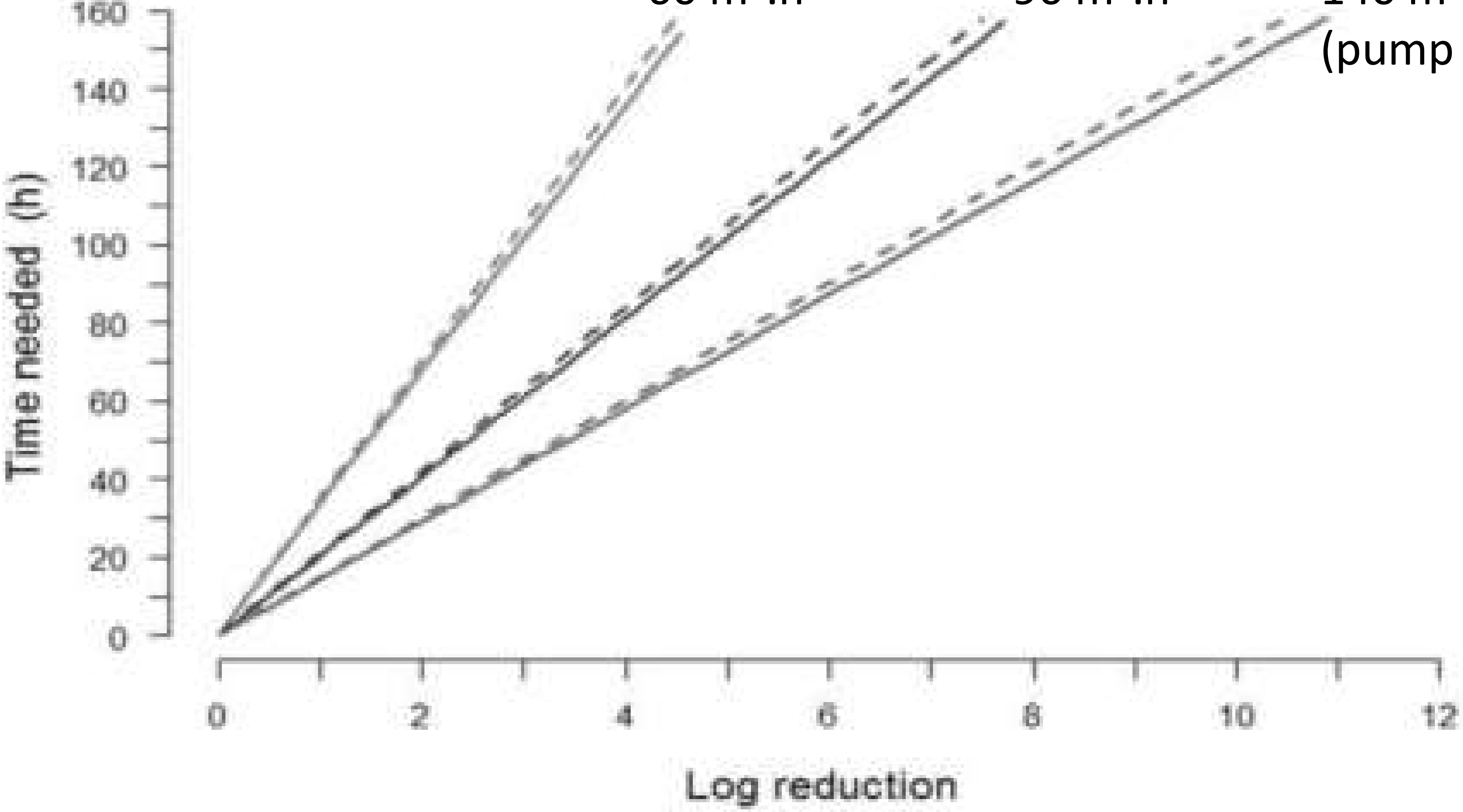
Source

Controls

Exposure

Health impacts

Time needed to reach a Log_{10} Reduction Value for three flow rates:



$60\ m^3.h^{-1}$

$90\ m^3.h^{-1}$

$140\ m^3.h^{-1}$ (pump max)

Source

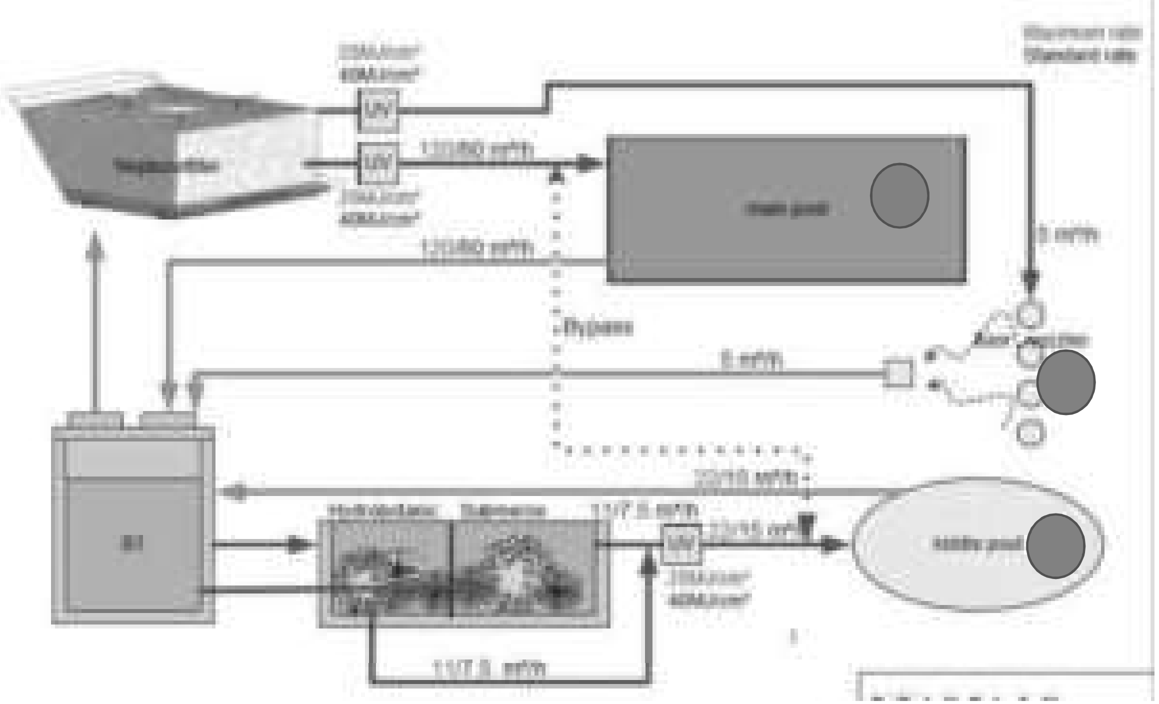
Controls

Exposure

Health impacts

Accidental faecal release (AFR)

- Modelled at various locations, with and without UV disinfection
- UV disinfection limited the spread of the impact



Source

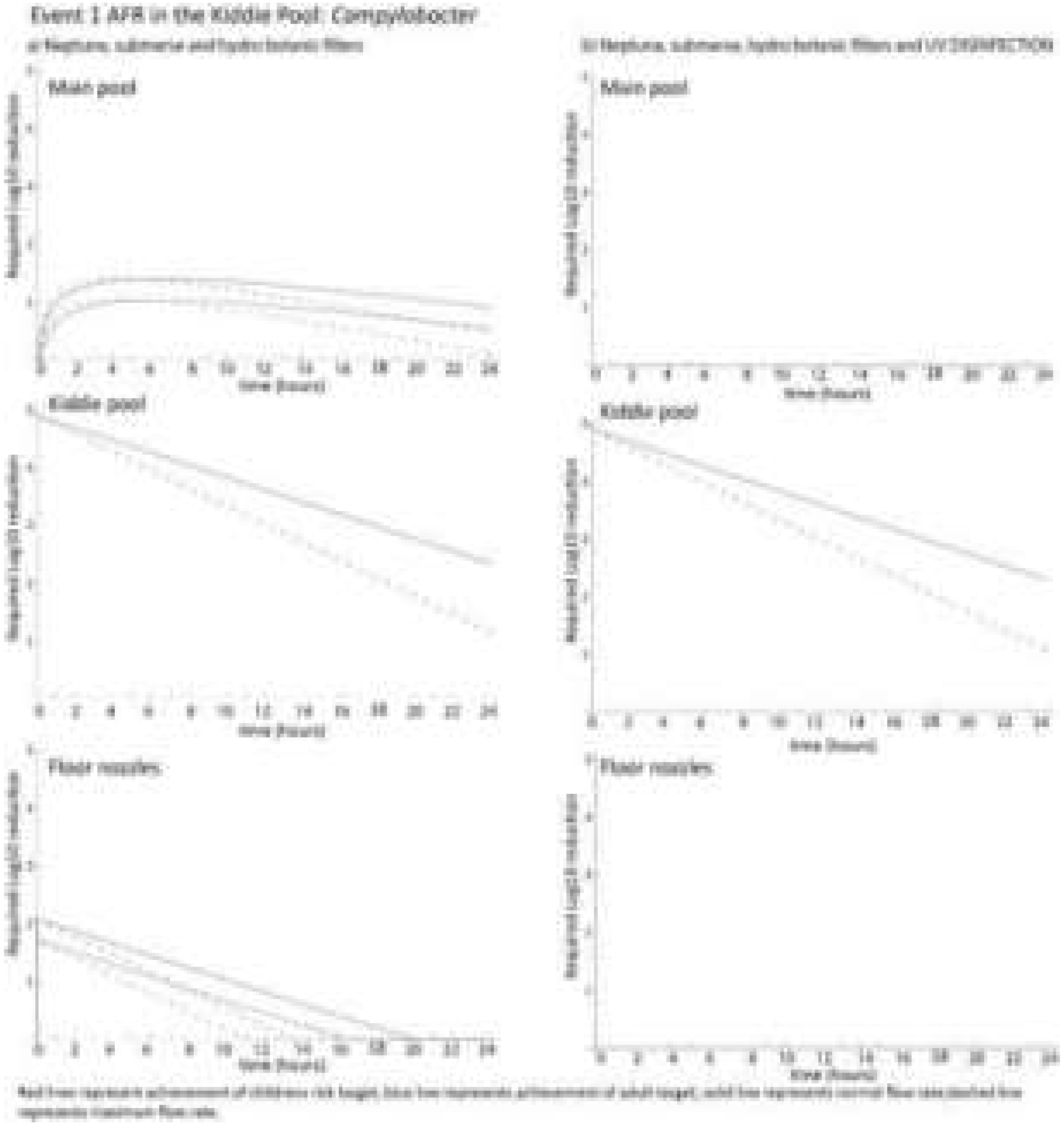
Controls

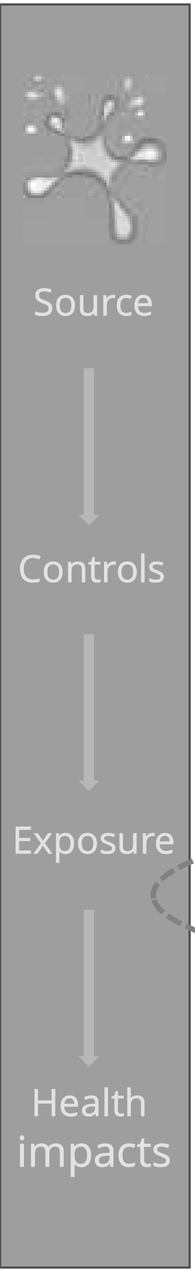
Exposure

Health impacts

Kiddie pool: accident

Campylobacter





Controls: conclusions

- Overall performance was driven by the flow rate through the external treatment system
- Addition of UV disinfection limited the spread of contamination
- Limited information is available regarding the performance of control measures?
- Understanding the performance of the **natural disinfection** is an important research gap

Source

Controls

Exposure

Health impacts

Spiking trials

- Neptune filter
- Hydro-botanic plant and submerse filters
- UV systems

Study reference pathogens & surrogates

Source

Controls

Exposure

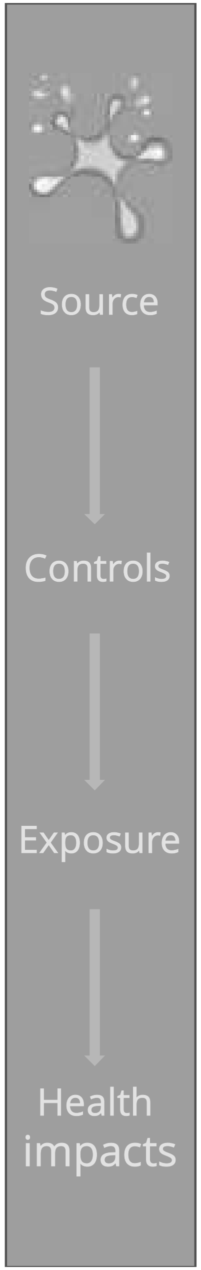
Health impacts

- Enteric virus reference pathogen: human *Norovirus*
  - **Surrogate**: MS2 coliphage (assayed as plaque-forming units & qPCR)
- Enteric bacteria reference pathogen: *Campylobacter jejuni*
  - **Surrogates**: *E. coli* and *Enterococcus faecalis* (Colilert™ & Enterolert ™ & total enterococci by qPCR)
- Parasitic protozoan reference pathogens: *Cryptosporidium & Giardia*
  - **Surrogate**: baker’s yeast (*Saccharomyces cerevisiae*) (as CFU)

Log-reduction value estimates from spiking

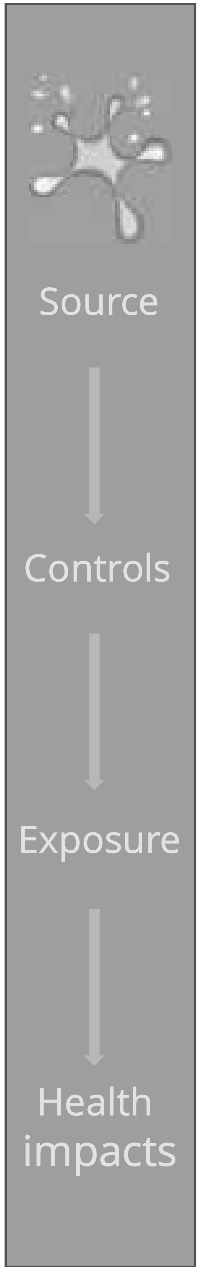
	Enterococcus	Enterococcus qPCR	Total MS2 qPCR	Viable Yeast
NF	1.48 (1.36, 1.60)	1.25 (1.13, 1.38)	1.35 (1.05, 1.82)	1.69 (1.54, 1.85)
HBF/SF	1.79 (1.75, 1.84)	1.86 (1.81, 1.91)	2.35 (2.21, 2.52)	1.84 (1.63, 2.01)
UV (Post NF)	> 4.02 (3.66, 4.62)	0.24 (0.09, 0.41)	*	>2.83 (2.49, 3.33)
UV (Post HBF/SF)	> 4.04 (4.01, 4.07)	0.04 (0.02, 0.06)	*	>2.77 (2.51, 3.17)

Mean and 95th confidence interval



Spiking trials

- Assumed values from literature were broader but generally within the value estimated from spiking study
- Virus removal was relatively low
- Bakers yeast appeared to be removed as expected for parasitic protozoan oo/cysts



Conclusions

- QMRA provided a useful framework for assessing pathogen risks associated with NSPs
- Overall treatment performance was limited by the **flow rate** through external treatment barriers
- Microbial surrogate challenge testing provided useful insights regarding full scale performance
- Understanding the performance of **natural disinfection** is an important research gap
- Risks can be minimised through **alternative management approaches**