

**QMRA of an indoor swimming pool  
Chlorination versus UV-based treatment (PPT)**

Peters, Marjolein; Keuten, Maarten; de Kreuk, Merle; Vrouwenvelder, Hans; Rietveld, Luuk; Medema, Gertjan

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# QMRA of an indoor swimming pool

## Chlorination versus UV-based treatment

# Alternative disinfection

- Good microbial water quality with UV-based treatment
- What are the risks of infection compared to chlorination?



Quantitative Microbial Risk Assessment  
(QMRA)

## QMRA parameters (swimming pool)

- Competition pool: 25x10x2 m<sup>3</sup>
- Turnover time:
  - Chlorinated: 4 h
  - UV-based treatment: 30 min
- bathing load: 40 bathers /h
- Swimming: 12h /day

## QMRA parameters (micro-organisms)

- *Campylobacter jejuni*
- *Escherichia coli* O157:H7
- *Salmonella enterica*
- *Cryptosporidium parvum*

# Micro-organism release

- Enterobacter release bathers: 9% (Peters et al. 2016)
- Intact cell release distribution (Keuten et al. 2013)
  - 0-5 min:  $3.0 \times 10^9$  intact cells → 1.06 g faecal matter
  - 6-10 min:  $2.7 \times 10^9$  intact cells → 979 mg faecal matter
  - 11-15 min:  $1.4 \times 10^9$  intact cells → 518 mg faecal matter
  - 16-20 min:  $1.3 \times 10^9$  intact cells → 473 mg faecal matter
  - 21-25 min:  $0.4 \times 10^9$  intact cells → 158 mg faecal matter
  - 26-30 min:  $0.4 \times 10^9$  intact cells → 143 mg faecal matter

# Pathogen release

- Faecal matter:  $10^8$  pathogens /g
- Pathogens within (de Wit et al. 2001):
  - *Campylobacter jejuni*: 1.3%
  - *Escherichia coli* O157:H7: 0.3%
  - *Salmonella enterica*: 0.4%
  - *Cryptosporidium parvum*: 0.1%
- Pool basin is homogeneously mixed

# QMRA parameters (bathers)

- Swim duration: 1h
- 59 swimming events per year
- 100% pre-swim shower
- Only continual release (no incidental)
- Water ingestion: 13,7 mL / bather (Suppes et al. 2014)
- Infection probability NL: 283/1000 (de Wit et al. 2001)



# Treatment

- Chlorination;
  - 3 log reduction in 1 minute (Blaser 1986)  
for *C. jejuni*, *E. coli* and *S. enterica*
  - *Cryptosporidium* removal by filtration  
1 log reduction per filter passage (Amburgey 2011)
- UV-based treatment
  - 5 log removal / inactivation per treatment

# Dose response models

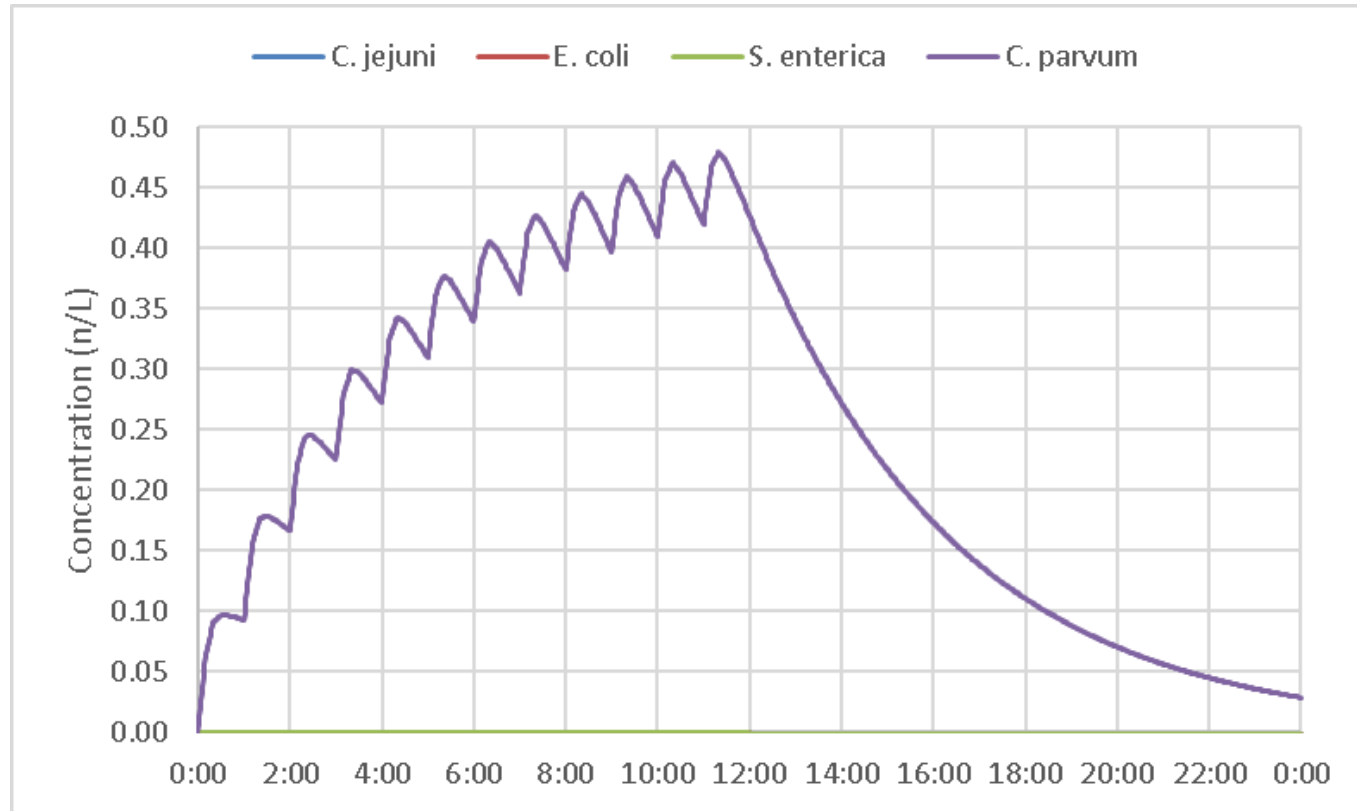
- Beta-Poisson model:

	$\alpha$	$\beta$	
<i>Campylobacter jejuni</i>	0.144	7285	(Black et al. 1988)
<i>Escherichia coli</i> O157:H7	0.155	24386	(DuPont et al. 1971)
<i>Salmonella enterica</i>	0.175	10776	(Hornick 1966, 1970)

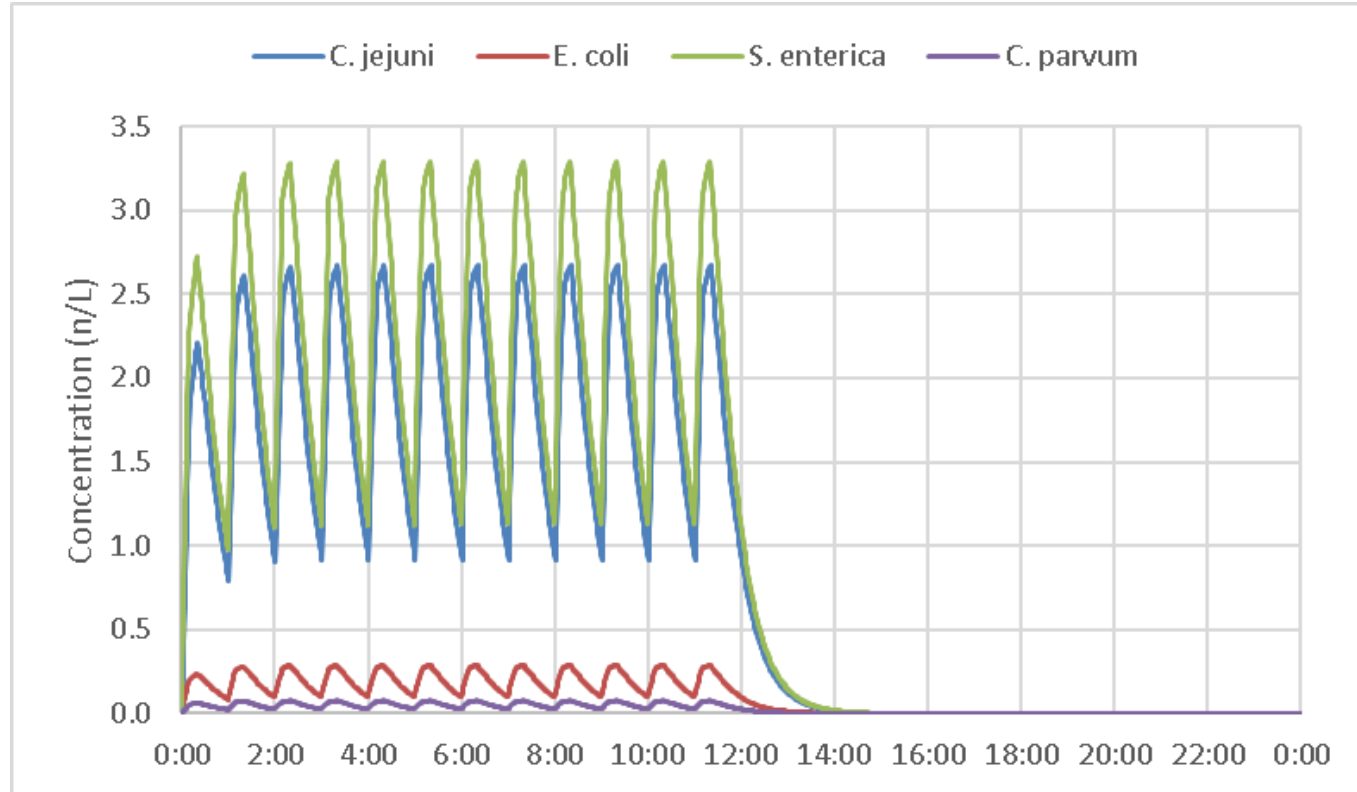
- Exponential model:

- *Cryptosporidium*;  $k = 0.057$  (Messner et al. 2011)

# Results chlorination



# Results UV-based treatment



# Results

		Average concentration (n/L)	Dose (n/swim)	Infection risk	Yearly infection risk
<i>C. jejuni</i>	Chlorination	$6.4 \times 10^{-5}$	$8.8 \times 10^{-7}$	$1.7 \times 10^{-11}$	$1.0 \times 10^{-9}$
	UV-based	1.8	$2.5 \times 10^{-2}$	$4.8 \times 10^{-7}$	$2.8 \times 10^{-5}$
<i>E. coli</i>	Chlorination	$6.9 \times 10^{-6}$	$9.5 \times 10^{-8}$	$6.0 \times 10^{-13}$	$3.6 \times 10^{-11}$
	UV-based	$2.0 \times 10^{-1}$	$2.7 \times 10^{-3}$	$1.7 \times 10^{-8}$	$1.0 \times 10^{-6}$
<i>S. enterica</i>	Chlorination	$7.9 \times 10^{-5}$	$1.1 \times 10^{-6}$	$1.8 \times 10^{-11}$	$1.0 \times 10^{-9}$
	UV-based	2.2	$3.1 \times 10^{-2}$	$5.0 \times 10^{-7}$	$3.0 \times 10^{-5}$
<i>C. parvum</i>	Chlorination	$3.3 \times 10^{-1}$	$4.6 \times 10^{-3}$	$4.3 \times 10^{-3}$	$1.5 \times 10^{-2}$
	UV-based	$5.2 \times 10^{-2}$	$7.2 \times 10^{-4}$	$6.9 \times 10^{-4}$	$2.4 \times 10^{-3}$

## Sensitivity analysis for *E. coli* (UV-based treatment)

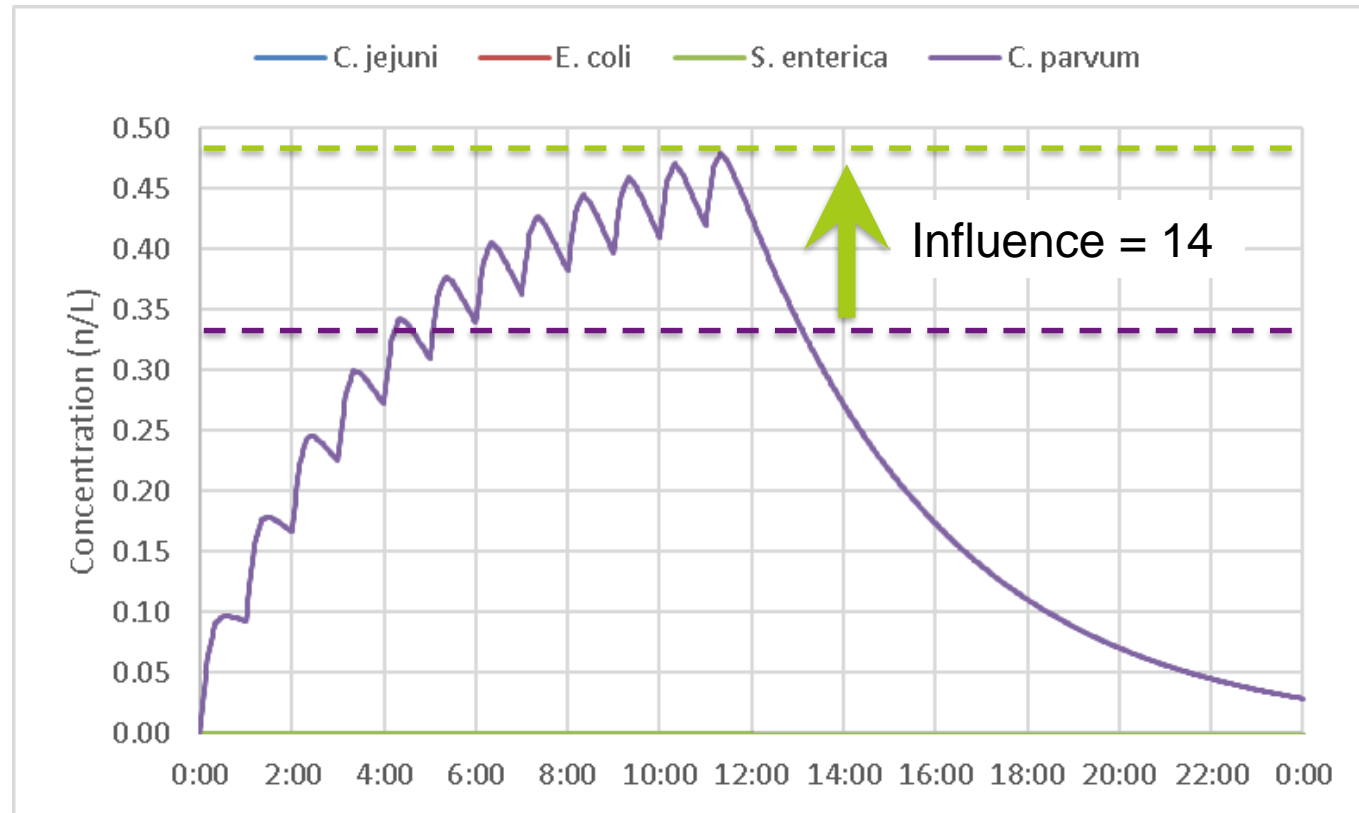
- Bathers / m<sup>3</sup>: 40/500 → 10/5 (toddler or hwp)
- Turnover time: 30 → 240 min
- Treatment: 5-log → 1-log reduction
- Swimming events: 59 → 260 /year (5/wk)
- Simultaneous bathers: 40 → 108
- Infected bathers: 2/40 → 11/40
- Ingested pool water: 13.7 → 51 mL
- *E. coli* in faecal matter: 0.3% → 10%
- Pathogens in faeces: 10<sup>8</sup> → 10<sup>10</sup>

# Results

## Sensitivity analysis for *E. coli*

	Value Ref.	Value worst case	P[inf] ref	P[inf] max	Value max/ref	P[inf] max/ref	Influence
Bathers / m <sup>3</sup>	12.5	0.5	1.0x10 <sup>-6</sup>	2.5x10 <sup>-5</sup>	0.04	25	625
Turnover time	30	240	1.0x10 <sup>-6</sup>	6.0x10 <sup>-6</sup>	8	5.95	0.7
Treatment eff.	0.99999	0.9	1.0x10 <sup>-6</sup>	1.1x10 <sup>-6</sup>	0.9	1.11	1.2
Swim events	59	260	1.0x10 <sup>-6</sup>	4.5x10 <sup>-6</sup>	4.4	4.4	1.0
Bathers	40	108	1.0x10 <sup>-6</sup>	2.7x10 <sup>-6</sup>	2.7	2.7	1.0
Infected bathers	5%	28%	1.0x10 <sup>-6</sup>	5.6x10 <sup>-6</sup>	5.56	5.56	1.0
Ingested water	13.7	51	1.0x10 <sup>-6</sup>	3.8x10 <sup>-6</sup>	3.72	3.7	1.0
<i>E.coli</i> % pathogens	0.3%	10%	1.0x10 <sup>-6</sup>	3.4x10 <sup>-5</sup>	33.3	33.4	1.0
Path.in faeces	10 <sup>8</sup>	10 <sup>10</sup>	1.0x10 <sup>-6</sup>	1.0x10 <sup>-4</sup>	100	100	1.0

# Moment of exposure





## Conclusions

- Yearly risk of infection with UV-based treatment higher than treatment with chlorination
- All risks  $<10^{-4}$ , except for *Cryptosporidium*
- For *Cryptosporidium*, best removal with UV-based treatment

Van Remmen  
UV Techniek

SPORTFONDSEN

CORAM



TU Delft

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Thanks for your attention

Questions ?