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Chlorination versus UV-based treatment

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QMRA of an indoor swimming pool

Chlorination versus UV-based treatment

Marjolein Peters¹, Maarten Keuten¹,², Merle de Kreuk¹, Hans Vrouwenvelder¹, Luuk Rietveld¹ and GertJan Medema¹
¹) Delft University ²) Hellebrekers Technieken
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 m³
- 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 $\rightarrow$ 1.06 g faecal matter
  - 6-10 min: $2.7 \times 10^9$ intact cells $\rightarrow$ 979 mg faecal matter
  - 11-15 min: $1.4 \times 10^9$ intact cells $\rightarrow$ 518 mg faecal matter
  - 16-20 min: $1.3 \times 10^9$ intact cells $\rightarrow$ 473 mg faecal matter
  - 21-25 min: $0.4 \times 10^9$ intact cells $\rightarrow$ 158 mg faecal matter
  - 26-30 min: $0.4 \times 10^9$ intact cells $\rightarrow$ 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:

<table>
<thead>
<tr>
<th></th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Campylobacter jejuni</em></td>
<td>0.144</td>
<td>7285</td>
<td>(Black et al. 1988)</td>
</tr>
<tr>
<td><em>Escherichia coli O157:H7</em></td>
<td>0.155</td>
<td>24386</td>
<td>(DuPont et al. 1971)</td>
</tr>
<tr>
<td><em>Salmonella enterica</em></td>
<td>0.175</td>
<td>10776</td>
<td>(Hornick 1966, 1970)</td>
</tr>
</tbody>
</table>

• Exponential model:
  – *Cryptosporidium*; $k = 0.057$ (Messner et al. 2011)
Results chlorination

Graph showing concentration levels over time for different organisms.
Results UV-based treatment

- C. jejuni
- E. coli
- S. enterica
- C. parvum

Concentration (n/L)

Time (0:00 to 24:00)

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

- Bathers / m$^3$: 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: $10^8$ → $10^{10}$
## Sensitivity analysis for *E. coli*

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

Moment of exposure

![Graph showing concentration over time for different organisms with an influence value of 14.]
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
Acknowledgements

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Questions?