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

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QMRA of an indoor swimming pool

Chlorination versus UV-based treatment

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1) Delft University 2) Hellebrekers Technieken
Introduction

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>Campylobacter jejuni</td>
<td>0.144</td>
<td>7285</td>
<td>(Black et al. 1988)</td>
</tr>
<tr>
<td>Escherichia coli O157:H7</td>
<td>0.155</td>
<td>24386</td>
<td>(DuPont et al. 1971)</td>
</tr>
<tr>
<td>Salmonella enterica</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 over time for different bacteria species](image-url)
Results UV-based treatment

![Graph showing the concentration of C. jejuni, E. coli, S. enterica, and C. parvum over time. The graph displays cycles of concentration peaks and troughs for each bacterium, indicating effectiveness of UV treatment.]
### 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/m³: 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>
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<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

Influence = 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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Thanks for your attention

Questions ?

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