Modelització dels aspectes sanitaris i anàlisi del cicle de vida de la recàrrega de l’aqüífer del Port de la Selva

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Topics for today

1. Microbial risk assessment
2. Presence of pharmaceutical residues
3. Life cycle assessment
Microbial risk assessment (World health organization approach)

- Safe vs. unsafe? → No!
- They’re is more than black/white or yes/no.
- Our approach:
  - We work with a lot with worst case assumptions.
  - Use probabilities (How sure are you?)
  - How sure are we, that the inhabitants of El Port are not harmed by microbial contamination?
  - WHO definition of “not harmed”:
    - Additional microbial risk: < 1 µDALY (e.g. less than 1 virus/100,000 L present in water)
Microbial risk assessment
(World health organization approach)

- **Direct pathogen measurements** (Salmonella, Giardia)
- **Indicator to pathogen ratio** (Norovirus, Rotavirus, Campylobacter)
- **Epidemiological data**
- **Pathogen concentration in influent**
- **Pathogen concentration in effluent**
- **Pathogen concentration after subsurface passage**
- **Pathogen concentration after chlorination**

Reduction in STP (sec. + Filtr. + UV), technical barrier

Reduction during MAR (natural barrier)

Reduction DW production (chlorination)

**Exposure scenarios** (number of exposure event, ingested volume)

**Probability of infection**

**Probability of disease**

Risk of disease

Severity factor for DALY calculation

Disease per infection ratio

**Dose-response model**

**Probability of infection**

**Probability of disease**

Risk of disease
Overview reuse scheme

Assumptions for raw sewage:
- Campylobacter: 1.000.000/L
- Rotavirus 31.000/L
- Cryptosporidium 10.000/L

What is log-reduction?

<table>
<thead>
<tr>
<th>Log</th>
<th>Removal</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90 %</td>
<td>100.000 /L</td>
</tr>
<tr>
<td>2</td>
<td>99 %</td>
<td>10.000 /L</td>
</tr>
<tr>
<td>3</td>
<td>99.9 %</td>
<td>1.000 /L</td>
</tr>
<tr>
<td>4</td>
<td>99.99 %</td>
<td>100 /L</td>
</tr>
<tr>
<td>5</td>
<td>99:999 %</td>
<td>10 /L</td>
</tr>
<tr>
<td>6</td>
<td>99.9999 %</td>
<td>1 /L</td>
</tr>
<tr>
<td>7</td>
<td>99.99999 %</td>
<td>0.1 /L</td>
</tr>
<tr>
<td>8</td>
<td>99.999999 %</td>
<td>0.01 /L</td>
</tr>
<tr>
<td>9</td>
<td>99.9999999 %</td>
<td>0.001 /L</td>
</tr>
<tr>
<td>10</td>
<td>99.99999999 %</td>
<td>0.0001 /L</td>
</tr>
</tbody>
</table>

Required reduction compared to raw sewage to reach 1 µDALY (log reduction):

- Campylobacter: 6.12
- Rotavirus 5.6
- Cryptosporidium 3.34
Microbiology data from El Port reuse site

- Royal degree for reuse fulfilled (infiltration)
- Good removal of bacteria during subsurface passage
- Little removal of bacteriophages in groundwater after short residence time (in line with literature → need longer time)

TT = mean travel time of infiltrate from pond to observation well
4/6 = four positive out of six samples
Example of performance assessment (Filter + UV disinfection)

Sampling campaigns in spring 2016

Performance and uncertainty assessment (example for bacteria reduction)

- Virtually certain > 99%
- Very likely > 90%

Required additional reduction after UV disinfection

<table>
<thead>
<tr>
<th>Reference pathogens for bacteria, viruses and parasites</th>
<th>Indirect potable reuse</th>
<th>Urban irrigation</th>
<th>Private irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campylobacter</td>
<td>4.88</td>
<td>1.9</td>
<td>0.3 - 1.27</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>3.65</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Cryptosporidium</td>
<td>3.3</td>
<td>- 0.7</td>
<td>- 0.4</td>
</tr>
</tbody>
</table>

- Virtually certain that log reduction for bacteria is > 2 log units for bacteria
- High confidence (79 - 98%) that reduction of bacteria by UV disinfection at least 2.6 log
  Uncertainty result of number of samples (n = 36). Reduction by taking more samples recommended.
- Reduction of parasites and viruses by 2.7 log and 3 log respectively

Physical disinfection
Reduction during subsurface passage (indirect potable reuse)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Distribution</th>
<th>Log Reduction</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traveltime</td>
<td>Range</td>
<td>N (μ = 500, sd = 100)</td>
<td>Model Amphos 21</td>
</tr>
<tr>
<td>Reduction during infiltration Campylobacter</td>
<td>Range</td>
<td>2 – 6 &lt;br&gt; Used value 2</td>
<td>WHO Guidelines for Drinking Water Quality</td>
</tr>
<tr>
<td>Reduction during subsurface passage Campylobacter</td>
<td>T90 &lt;br&gt; 3d - 7d</td>
<td>&gt; 20 &lt;br&gt; Used value 20</td>
<td>Sidhu et al. 2015, from diffusion chamber experiments of 4 different MAR sites</td>
</tr>
<tr>
<td>Reduction during infiltration Cryptosporidium</td>
<td>Range</td>
<td>0.5 - 5 &lt;br&gt; Used value 0.5</td>
<td>WHO Guidelines for Drinking Water Quality</td>
</tr>
<tr>
<td>Reduction during subsurface passage Cryptosporidium</td>
<td>T90 &lt;br&gt; 56-120d</td>
<td>4.2 - 8.9 &lt;br&gt; Used value 4.2</td>
<td>Sidhu et al. 2015 from diffusion chamber experiments of 4 different MAR sites</td>
</tr>
<tr>
<td>Reduction during infiltration Rotavirus</td>
<td>Range</td>
<td>0.25 - 4 &lt;br&gt; Used value 0.25</td>
<td>WHO Guidelines for Drinking Water Quality</td>
</tr>
<tr>
<td>Reduction during subsurface passage Rotavirus</td>
<td>T90 = random &lt;br&gt; (min = 30, max = 100)</td>
<td>&gt; 5 log</td>
<td>Australian Guidelines for Water recycling</td>
</tr>
<tr>
<td>Reduction chlorination (drinking water treatment)</td>
<td>Point estimate</td>
<td>2 log viruses 2 log bacteria 0.5 log protozoa</td>
<td>WHO Guidelines for Drinking Water Quality</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference pathogens</th>
<th>WWTP, UV, MAR, CI</th>
<th>WWTP, MAR, UV (failure of CI at DWTP)</th>
<th>WWTP, MAR, CI (failure of Filter + UV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campylobacter</td>
<td>-19.12</td>
<td>-17.12</td>
<td>-16.52</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>- 3.55</td>
<td>- 1.55</td>
<td>0.2</td>
</tr>
<tr>
<td>Cryptosporidium</td>
<td>- 2</td>
<td>- 1.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Conclusions Microbial Risk Assessment

• The required log reduction for bacteria, virus and parasites can be achieved for all three reuse options:
  – In line with WHO target of 1µDALY
  – Even with worst case assumptions (high initial concentration + low performance of treatment steps) → real risk will be most likely much lower
  – But: All treatment steps need to be in operation!

• Most critical treatment step is the filter + UV disinfection:
  – If UV disinfection fails, the reuse of water has to be stopped (for both irrigation and infiltration)
  – In 2013-2014 in some cases very low disinfection performance (UV lamps replaced in 2014) → room for improvement
## Estimation on trace organic transfer from secondary effluent via MAR to drinking water well

<table>
<thead>
<tr>
<th>Trace organics</th>
<th>Secondary Effluent (µg/L)</th>
<th>Estimate drinking water (µg/L)</th>
<th>Health orientated guideline value in Germany (µg/L) **</th>
<th>Prediction with activated carbon treatment (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbamazepine</td>
<td>0.2</td>
<td>0.005 - 0.08 (Median 0.04)</td>
<td>0.3</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Gabapentine*</td>
<td>1.6</td>
<td>0.17-0.63 (Median 0.36)</td>
<td>1.0</td>
<td>0.08-0.35 (Median &lt; 0.2)</td>
</tr>
<tr>
<td>Sulfamethoxazole</td>
<td>0.84</td>
<td>±0.050</td>
<td>0.1</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Diuron</td>
<td>2.3</td>
<td>0 – 0.002 (Median: 0.001)</td>
<td>0.1</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Terbutryne</td>
<td>0.15</td>
<td>0-0.0008 (Median: 0.0005)</td>
<td>0.1 (legal limit)</td>
<td>&lt; 0.00005</td>
</tr>
</tbody>
</table>

*assumption: no degradation in MAR (worst case assumption) → degradable, but no degradation coefficient known yet

**Health orientated guideline value: considered to be safe for 70 a of consumption by German EPA

GAC with max. 5000 BV
Conclusion on trace organic contaminants

- Various trace organic contaminants present in WWTP effluent
- Without additional treatment step:
  - Transfer of pesticides unlikely
  - Transfer of pharmaceutical residues very likely, but still below health orientated guideline values from German EPA
- Planning for full-scale activated carbon filter ongoing (pilot test this summer, lab test for GAC selection performed by KWB)
- With additional treatment step (Prediction based on piloting in Berlin):
  - Additional safety barrier against pesticides
  - Transfer of pharmaceutical strongly reduced (Carbamazepine, Sulfamethozazol), most difficult compound to be removed is Gabapentine
Comparison of treatment option
El Port de la Selva

Fabian Kraus, 05/2016
Methodology of LCA

- **LCA** is a standardized holistic tool to assess direct and indirect effects.
- **LCA** considers chemical & electricity production, infrastructure...
- **Balancing** ecological benefits vs. ecological burdens.
  - e.g. reduction of water scarcity vs. increased energy consumption.

**Emissions** in air, water, soil

**System boundaries**

- **Climate change**
- **Acidification**
- **Eutrophication**
- **Human & Ecotoxicity**

**Electricity, Chemicals**

**Waste disposal**

**Product system**
  - e.g. tertiary treatment

**Resources** (fossil fuels, ores, land use)

**Co-Products**
  - (electricity, nutrients...)

**Cum. Energy Demand**
  - Abiotic resource depletion
  - Land use
Scope of LCA for El Port de la Selva:

„Analysis of the alternatives to increase the availability of water resources in El Port de la Selva by 100 Mio liters/year”
0. **status** until 2015
   - WWTP effluent discharge to sea, drinking water from groundwater

1. **reuse A** with filter, GAC, UV (and Cl) in tertiary treatment
   - partial WWTP effluent irrigation to private gardens (summer)
   - partial WWTP effluent infiltration into aquifer (winter)

2. **reuse B** with UF, RO (and Cl) in tertiary treatment
   - partial WWTP effluent irrigation to gardens (summer)
   - partial WWTP effluent infiltration into aquifer (winter)

3. **network connection**
   - Pumping water from Empuriabrava

4. **seawater desalination**
global warming potential

**Total Spain:** approx. 8000 kg CO₂-Eq/(pe*a)

**Total EU-27:** approx. 11000 kg CO₂-Eq/(pe*a)

Data-Set and total value from 2008
global warming potential and ionising-radiation of Reuse A for different electricity mixes of...

Data-Set and total value from 2008
Conclusion life cycle assessment

- All measures to increase water availability are associated with additional energy consumption and greenhouse gas emissions (only other solution: reduce water consumption)
- Ranking of GHG emissions:
  - Seawater desalination >> wastewater desalination/pipeline from Empuriabrava/ infiltration
  - High exchange rate of activated carbon makes wastewater desalination an potential alternative to current scheme
- A high share of renewable energy in the national energy mix reduces the GHG emissions
- Options to reduce GHG emissions:
  - Direct pipeline from WWTP to infiltration pond
  - Replacement of pressurized filtration by gravity sand filter (reduction of energy demand)
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