Characterization and Quantification of Microbial Risks: Rainwater/stormwater

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Technologies & Innovative Solutions for Harvesting and Non-Potable Use of Rain & Stormwater in Urban Settings
Session 3: Duke Center, Cincinnati April 25, 2013
Problems with water monitoring

- Tests results received after water used
- Too many parameters for frequent testing & the only microbial indicator included is *E. coli*
  - But *E. coli* is a poor indicator for viral and protozoan pathogen removal/inactivation & does not indicate presence of environmental pathogens (e.g. *Legionella*).
- For many hazards there is no suitable test

Therefore use a risk management approach
QMRA – Analytic Framework

- Explore system risks (QMRA)
- Reassess system
- Prioritize system risks (harmonize)
- Research knowledge gaps
- Identify control surrogates & control levels
Quantitative microbial risk assessment (QMRA)

**Problem formulation & Hazard identification**
Describe physical system, selection of reference pathogens and identification of hazardous events

**STEP 1**

**SETTING**

**STEP 2**

**EXPOSURE**

Rain / Storm water
Pathogen concentrations

Ingress
Ingress pathogen

(P$_{\text{ingress}}$)

Cistern storage
Pathogen loss
(sediment/biofilm/death)

Treatment (UV/Cl$_2$)
Pathogen removal

Non-Potable exposures
Volume water consumed

**STEP 3**

**HEALTH EFFECTS**

Dose-Response (P$_{\text{inf}}$)
Selection of appropriate models for each pathogen and the population exposed

**STEP 4**

**RISK**

Risk Characterisation
Simulations for each pathogen baseline and event infection risks with variability & uncertainty identified
Grounding from epi studies

Indicator? ← Exposure ← Outcome

Hazard identification & characterization
Describe physical system, selection of reference pathogens and identification of hazardous events

STEP 1
SETTING

Rodrigo et al. (2011) Amer J Pub Health 101(5), 842-847

No
Epi provides disease data – Limited on pathogens

- Gastroenteritis
- Respiratory
- Skin, eye infections
- Neurological
  - Other sequellae

Including non-GI disease requires a common metric (DALY)
Focus now on exposure reconstruction (saliva, sera etc.)
Drinking water public health costs

- CDC estimate waterborne disease costs > $970 m/y
  - Addressing giardiasis, cryptosporidiosis, Legionnaires’ disease, *otitis externa*, and non-tuberculous mycobacterial (NTM) infections, causing over 40 000 hospitalizations per year

<table>
<thead>
<tr>
<th>Disease</th>
<th>$ / hospitalization</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptosporidiosis</td>
<td>$16 797</td>
<td>$45 770 572</td>
</tr>
<tr>
<td>Giardiasis</td>
<td>$9 607</td>
<td>$34 401 449</td>
</tr>
<tr>
<td>Legionnaires’ disease</td>
<td>$33 366</td>
<td>$433 752 020</td>
</tr>
<tr>
<td>NTM infection/Pulmonary</td>
<td>$25 985 / $25 409</td>
<td>$425 788 469 / $194 597 422</td>
</tr>
</tbody>
</table>

Collier et al. (2012) Epi Inf 140(11), 2003-2013
Rainwater pathogen estimates

<table>
<thead>
<tr>
<th>Reference Pathogen</th>
<th>Range (% +ve /#)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Salmonella enterica</em></td>
<td>0.9% /125 – 11% /27</td>
</tr>
<tr>
<td><em>Campylobacter jejuni</em></td>
<td>ND /125 – 45% /27</td>
</tr>
<tr>
<td><em>E. coli</em> O157:H7</td>
<td>ND (not detected)</td>
</tr>
<tr>
<td><em>Cryptosporidium parvum</em></td>
<td>ND – 35% /17</td>
</tr>
<tr>
<td><em>Giardia intestinalis</em></td>
<td>ND /125 – 19% /21</td>
</tr>
<tr>
<td><em>Legionella</em> spp. (few L. pneumophila)</td>
<td>ND /125 – 26% /27</td>
</tr>
</tbody>
</table>

Fecal pathogens all event driven, i.e. washed-in roof scats
Use culture & PCR data to bound credible ranges
Rationale for indicator qPCR vs pathogen detection – in stormwater (~ 100-fold)

- Target pathogen density (rec water 0.03 GI risk swim\(^{-1}\))
  - e.g. for one of the most numerous sewage pathogens:
    - 9 *Norovirus* genomes L\(^{-1}\) of rec water \(\Rightarrow\) 0.03 GI risk
      - Changing *Norovirus* morbidity based on infection from best estimate 0.6 to 0.1 increases target density to 80 *Norovirus* genomes L\(^{-1}\) (half to a tenth if recovery accounted for)

- *Bacteroides* HF183 target for same level of contamination from sewage to cause the benchmark (0.03 GI) illness:
  - 8600 *Bacteroides* HF183 genome copies L\(^{-1}\)

Rain/Storm water fecal indicators

• Microbial source tracking markers
  – General & avian fecal markers
    • various *Bacteroidales* PCRs however, no avian targets
    • *Catellicoccus* PCR or cholesterol markers for avian excreta
  – Sewage-targeted (various *Bacteroides*, *e.g.* HF183)

• Surrogates for pathogen removals
  – Baker’s yeast for *Crypto* & *Giardia* oo/cysts
  – Bacteriophages for human enteric viruses
Surrogates for stormwater treatment

• Three stormwater recycling systems evaluated*, which included biofiltration, storage tanks, UV disinfection, constructed wetland, retention ponds

• Barrier efficacy studied by MS2, yeast & *E. coli*
  – Over 12 mo under wet & dry conditions, e.g. biofilter log-reductions

<table>
<thead>
<tr>
<th>Replicate</th>
<th>MS2 phage</th>
<th>E. coli</th>
<th>Yeast</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>1.8</td>
<td>2.9</td>
</tr>
<tr>
<td>2</td>
<td>1.2</td>
<td>1.6</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Rainwater reference pathogens

Dose-Response data, and find...

- *Campylobacter* more important than *Salmonella*
- Toxigenic *E. coli* very infectious, but rare
- *Cryptosporidium* probably > *Giardia*
- Of the viruses, possibly bird flu of interest
- Of environmental pathogens, only *L. pneumophila* dose-response data available
Hazardous events vs nominal

• Enteric pathogen risks depend upon:
  – ID and control of short-duration hazardous events throughout the system; via
  – Surrogate target levels (at control points)
    • Rainwater: is disinfection on/functioning?
    • Stormwater: are barriers intact/functioning?

• Environmental pathogen risk is largely a function of chronic conditions
  – Warm stagnant water/biofilms-nutrients
QMRA – Analytic Framework

1. Explore system risks (QMRA)
2. Prioritize system risks (harmonize)
3. Identify control surrogates & control levels
4. Research knowledge gaps
5. Reassess system

Diagram:
- Explore system risks (QMRA)
- Prioritize system risks (harmonize)
- Identify control surrogates & control levels
- Research knowledge gaps
- Reassess system

Flow:
1. Explore system risks (QMRA) → Prioritize system risks (harmonize) → Identify control surrogates & control levels → Research knowledge gaps → Reassess system → Explore system risks (QMRA)
Conclusions: research gaps

• Need qPCR estimates of infectious pathogens and generally, precision estimates
• Need to correlate qPCR targets/surrogates to specific pathogens by environment type (fate)
• Hence, need to identify primary risks of concern and their control parameters for effective rain & storm water management