SWIMMING-RELATED HEALTH RISKS AND RECREATIONAL WATER QUALITY CRITERIA

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CLEAN WATERS INITIATIVE WORKSHOP
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KEY TOPICS

Origins and Development of Pathogen Indicators

Health Risks and Water Quality Standards

Methods Development and Current Research

Alternative Indicators and Pathogens of Concern
Is it safe to swim here?

Pathogen indicator
“substance that indicates the potential for human infectious diseases”

Indicator illness risks determined through epidemiological studies

GOAL : protection of human health
1948  Epidemiological Studies
   Mean density of 2300 most probable number (MPN) per 100 mL of total coliforms associated with a detectable gastrointestinal illness (GI) rate

1968  National Technical Advisory Committee
   Converted to fecal coliforms using a 1:5 ratio geometric mean 400 MPN fecal coliform

   Reduced geomean to 200 MPN fecal coliform to bring illness rate to zero

   Single sample maximum of 400 MPN fecal coliform
ORIGINS AND DEVELOPMENT OF PATHOGEN INDICATORS

1986 AMBIENT WATER QUALITY CRITERIA FOR BACTERIA

1986 Fecal coliform not correlated with GI

*E. coli* and *Enterococcus* - strong correlation with gastroenteritis

![Figure 1.1 Fecal Coliform and Illness Rates](image1)

![Figure 1.3 E. coli and Illness Rates](image2)
Text Box 1. Translation of 1960s criteria to 1986 criteria.

The 1986 criteria values ($A$) were derived as follows:

$$A = \frac{(B^n \cdot C)}{D}$$

Where:
- $B$ is the observed GM enterococci (from epidemiological studies).
- $C$ is the criterion for fecal coliform (200 cfu per 100 mL).
- $D$ is the observed GM fecal coliform (from epidemiological studies).

geomean

\[\text{cfu} = \text{colony forming units, equivalent to MPN}\]
ORIGINS AND DEVELOPMENT OF PATHOGEN INDICATORS

1986 AMBIENT WATER QUALITY CRITERIA FOR BACTERIA

1968 criteria translated using proportion equation for an equivalent risk level for selected indicators

Accepted risk levels:

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Illness rate</th>
<th>Risk level</th>
<th>Geomean</th>
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</thead>
<tbody>
<tr>
<td><em>E. coli</em></td>
<td>8/1000</td>
<td>0.8%</td>
<td>126 cfu per 100 mL</td>
</tr>
<tr>
<td><em>E. coli</em></td>
<td>10/1000</td>
<td>1.0%</td>
<td>206 cfu per 100 mL</td>
</tr>
<tr>
<td><em>Enterococcus</em></td>
<td>19/1000</td>
<td>1.9%</td>
<td>35 cfu per 100 mL</td>
</tr>
</tbody>
</table>

*cfu = colony forming units, equivalent to MPN*
Human Health Endpoint Criteria Definitions

1986 *Highly Credible Gastrointestinal Illness (HGCI)*

“any one of the following unmistakable or combinations of symptoms [within 8 - 10 days of swimming]: (1) vomiting (2) diarrhea with fever or a disabling condition (remained home, remained in bed or sought medical advice because of symptoms), (3) stomachache or nausea accompanied by a fever”

2012 *NEEAR-GI illness (NGI)*

“any of the following [within 10 - 12 days after swimming]: (a) diarrhea (three or more loose stools in a 24 hour period), (b) vomiting, (c) nausea and stomachache, or (d) nausea or stomachache and impact on daily activity”
HEALTH RISKS AND WATER QUALITY STANDARDS

Human Health Endpoint

**NEEAR-GI illness (NGI) 2012 Criteria**

“any of the following [within 10 - 12 days after swimming]: (a) diarrhea (three or more loose stools in a 24 hour period), (b) vomiting, (c) nausea and stomachache, or (d) nausea or stomachache and impact on daily activity”

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<tr>
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</table>
Figure 1.2 Exposure - Response

- EPA Recommended Criterion Risk Range

Swimming-Associated Illness Rate (% Contracting Illness)

Water Quality Indicator Density
HEALTH RISKS AND WATER QUALITY STANDARDS

- **BEACH ACT**
  - Required EPA to publish new or revised water quality criteria recommendations by October 15, 2012
  - Required EPA to complete epi studies in marine waters in a tropical region, and marine waters in a temperate region impacted by urban runoff
    - Rapid method *quantitative polymerase chain reaction* (QPCR)
    - Compares culture method results to QPCR results for several indicators: *Enterococcus, Bacteroides, Bacteroidales, Clostridium spp.*
Epidemiological Studies for 2012 Recreational Water Quality Criteria

- Marine temperate sites with point source sewage discharge (MS, AL, RI)
  - Significant risk of GI illness correlated with *Enterococcus* and *Bacteroidales* QPCR
- Great Lakes point source WWTP effluent
  - Positive associations with *Enterococcus* QPCR and GI illness
- Marine studies (South Carolina – urban runoff; Puerto Rico – tropical)
  - PR no positive trends observed
  - Positive but not significant relationship between GI illness and culture *Enterococcus*,
    - Same trend for *Enterococcus* QPCR and *Bacteroidales* QPCR
<table>
<thead>
<tr>
<th>Texas Contact Recreation Categories</th>
<th></th>
<th>Health Risks and Water Quality Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCR</td>
<td>Primary Contact Recreation (PCR)</td>
<td>significant risk of ingestion (swimming, wading by children, tubing, handfishing)</td>
</tr>
<tr>
<td>SCR 1</td>
<td>Secondary Contact Recreation 1 (SCR 1)</td>
<td>limited body contact (fishing, kayaking, boating)</td>
</tr>
<tr>
<td>SCR 2</td>
<td>Secondary Contact Recreation 2 (SCR 2)</td>
<td>body contact limited due to physical characteristics of water body or limited public access (fishing, kayaking, boating)</td>
</tr>
<tr>
<td>NCR</td>
<td>Noncontact Recreation (NCR)</td>
<td>limited body contact often due to unsafe conditions such as barge traffic (hiking, birding)</td>
</tr>
</tbody>
</table>
HEALTH RISKS AND WATER QUALITY STANDARDS

Criteria for Indicator Bacteria in the TCEQ Water Quality Standards

<table>
<thead>
<tr>
<th>Use Category</th>
<th>$E.\ coli$ per 100 ml (freshwater)</th>
<th>$\text{Enterococci per } 100\ \text{ml}$ (saltwater)</th>
<th>$\text{Enterococci per } 100\ \text{ml}$ (high saline inland waters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geo. mean</td>
<td>Derivation</td>
<td>Geo. mean</td>
</tr>
<tr>
<td>PCR</td>
<td>126</td>
<td>EPA criterion</td>
<td>35</td>
</tr>
<tr>
<td>SCR1</td>
<td>630</td>
<td>5 x PCR</td>
<td>175</td>
</tr>
<tr>
<td>SCR2</td>
<td>1,030</td>
<td>5 x 206 [PCR2]*</td>
<td>---</td>
</tr>
<tr>
<td>NCR</td>
<td>2,060</td>
<td>2 x SCR2</td>
<td>350</td>
</tr>
</tbody>
</table>

* PCR2 – same activities as PCR but occur less frequently due to limited public access or physical characteristics of the water body

* Not yet approved by EPA
HEALTH RISKS AND WATER QUALITY STANDARDS

Texas Coastal Recreation Water Quality Standards

- Follows 2012 EPA Recreational Water Quality Criteria
- Enterococci geomean 35 cfu, statistical threshold value 130 cfu
  - Illness rate 36/1000 – 3.6 % risk level
- Beach Action Value (BAV): 104 cfu Enterococci per 100 mL
  - for beach advisories
  - approximates 75th percentile of water quality distribution
METHODS DEVELOPMENT AND CURRENT RESEARCH

NON POINT SOURCES OF PATHOGENS

- **Quantitative Microbial Risk Assessment (QMRA)**
  - tool to conduct risk assessment for water-based media
  - used by researchers and government to explore management alternatives

![Diagram showing non-point sources of pathogens](image)

*Fig. 1. Schematic exposure diagram for hypothetical recreation at agricultural animal-impacted waterbody.*

Soller et al. 2015
Non Point Sources of Pathogens

- **Quantitative Microbial Risk Assessment (QMRA)**
  - tool to conduct risk assessment for water-based media
  - used by researchers and government to explore management alternatives

- “Human enteric viruses, in particular viruses with similar infectivity and incubation period to norovirus, were likely etiologic agents of observed recreational waterborne illness” (Soller et al. 2010)

- Health risks driven by proportion of contamination source with greatest ability to cause human infection, not necessarily greatest source of FIB (Soller et al. 2014)
Soller et al. 2015

QMRA

Fig. 5. Relative QMRA probability of illness boxplot. Note: edges of box represent 25th and 75th percentiles, diamonds represent 5th and 95th percentiles.
Enterococcus levels associated with illness levels of 36/1000 driven by proportion of human source
Fig. 6 – Run 3 contribution of each pathogen. Run 3 contribution of each reference pathogen to the probability of GI illness from ingestion of water containing fresh faecal pollution from animals or sewage at faecal indicator densities of 35 cfu 100 mL⁻¹ ENT (6A) and 126 cfu 100 mL⁻¹ E. coli (6B).
Exposure to water with direct cattle waste similar to risk from human waste

Fig. 5 – Run 3 probability of GI illness. Run 3 probability of GI illness from ingestion of water containing fresh faecal pollution at densities of 35 cfu 100 mL⁻¹ E. coli (S). Predicted risk (median, interquartile range, 10th and 90th percentiles, and 5th and 95th percentiles) for fresh gull, cattle and pig faeces, and chicken litter. Human impacts are presented for primary sewage (Human 1) and secondary disinfected effluent (Human 2). The Illness Benchmark represents a geometric mean probability of illness of 0.03.
**METHODS DEVELOPMENT AND CURRENT RESEARCH**

*Enterococci concentrations over 24 hours measured by QPCR*

**FIGURE 1.** ENT time series analyzed in the present study. Shaded areas represent 95% confidence intervals about each measurement as determined from MPN tables, black line is measured ENT. Heavy black line is tide level (shown on right axes). The code in the upper right corner describes the location and time of experiments (see Table 1).
ALTERNATIVE INDICATORS

- Coliphage
  - non-pathogenic indicators of fecal origin
  - bacteriophages that infect E. coli
    - Somatic or F-specific – two EPA methods for each
  - relationship to GI
  - abundant in sewage
  - do not re-grow in surface waters
  - inexpensive quantification in ~8 hours
PATHOGENS OF CONCERN

- human enteric viruses – norovirus, rotaviruses, adenoviruses
- *E. coli* O157:H7
- *Giardia lamblia*
- *Cryptosporidium* spp.
- *Campylobacter jejuni*
- *Salmonella enterica*
- Natural waters have inherent risk of illness
- Accepted risk level for water quality standards based off fecal coliform studies
- Proportion of human waste is significant factor for risk of illness
  - probability of illness from nonpoint source contamination variable
- Viral indicators in development
- Bacteria and pathogen indicator concentrations variable in recreational waters

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REFERENCES


THANK YOU FOR LISTENING

WHAT QUESTIONS DO YOU HAVE?

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