SWIMMING-RELATED HEALTH RISKS AND RECREATIONAL WATER QUALITY CRITERIA

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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

ORIGINS AND DEVELOPMENT OF PATHOGEN INDICATORS

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

ORIGINS AND DEVELOPMENT OF PATHOGEN INDICATORS

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
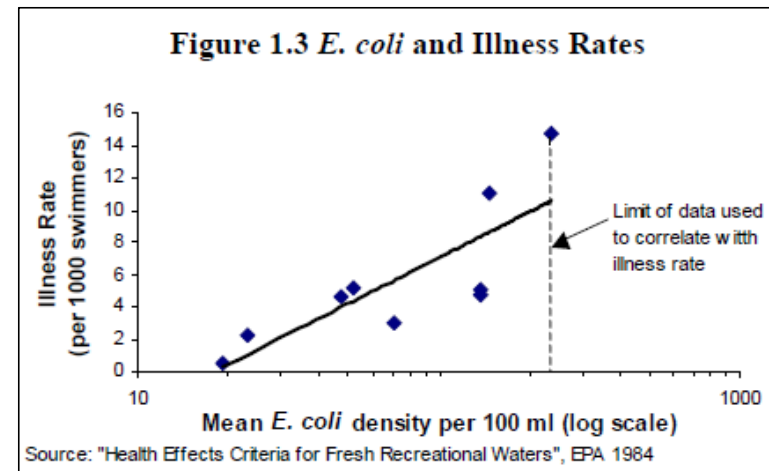
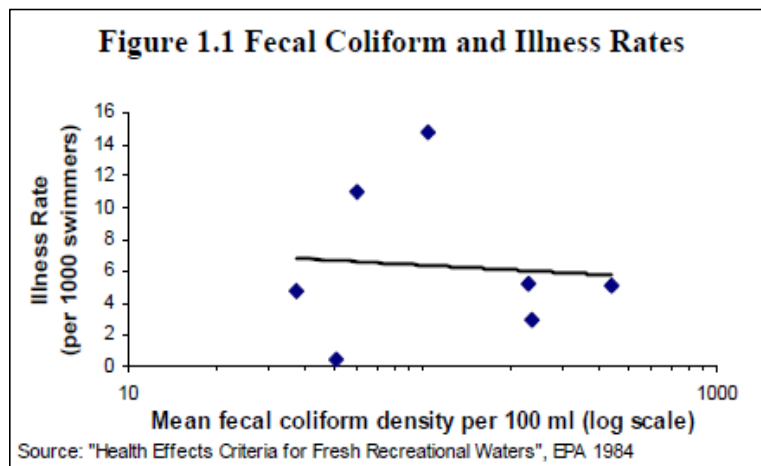Single sample maximum of 400 MPN fecal coliform

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

Illness Rate (per 1000 swimmers) vs Mean fecal coliform density per 100 ml (log scale)

Source: "Health Effects Criteria for Fresh Recreational Waters", EPA 1984

Figure 1.3 *E. coli* and Illness Rates

Illness Rate (per 1000 swimmers) vs Mean *E. coli* density per 100 ml (log scale)

Limit of data used to correlate witth illness rate

Source: "Health Effects Criteria for Fresh Recreational Waters", EPA 1984

ORIGINS AND DEVELOPMENT OF PATHOGEN INDICATORS

Text Box 1. Translation of 1960s criteria to 1986 criteria.

The 1986 criteria values (A) were derived as follows
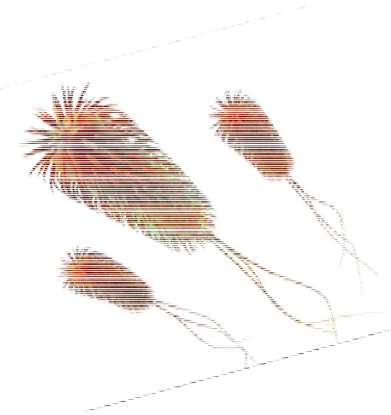
$$A = (B*C) / D$$

Where

B is the observed GM enterococci (from epidemiological studies)

C is the criterion for fecal coliform (200 cfu per 100 mL) **geomean**

D is the observed GM fecal coliform (from epidemiological studies)

cfu = 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:

Indicator	Illness rate	Risk level	Geomean
E. coli	8/1000	0.8%	126 cfu per 100 mL
E. coli	10/1000	1.0%	206 cfu per 100 mL
Enterococcus	19/1000	1.9%	35 cfu per 100 mL

cfu = colony forming units, equivalent to MPN

HEALTH RISKS AND WATER QUALITY STANDARDS

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"

| Indicator	Illness rate	Risk level	Geomean
E. coli	36/1000	3.6%	126 cfu per 100 mL
Enterococcus	36/1000	3.6%	35 cfu per 100 mL

HEALTH RISKS AND WATER QUALITY STANDARDS

Figure 1.2 Exposure - Response
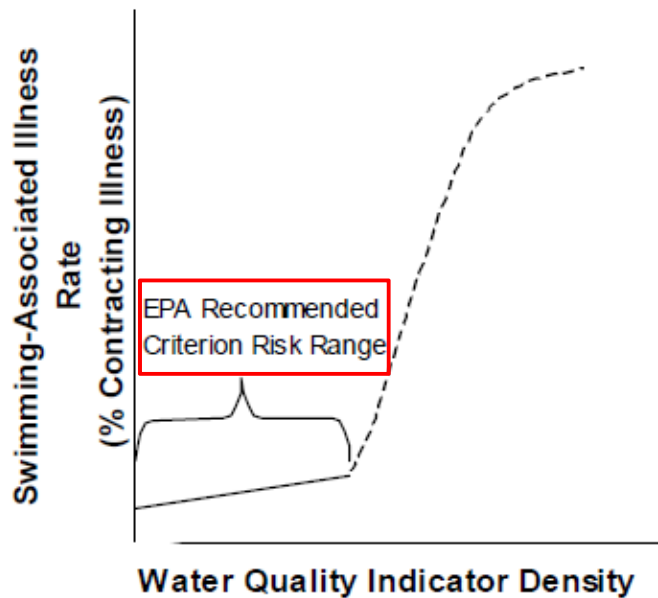
HEALTH RISKS AND WATER QUALITY STANDARDS

- 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.*
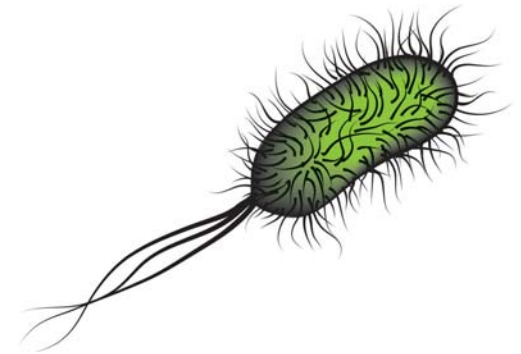
ENTEROCOCCUS FAECALIS

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HEALTH RISKS AND WATER QUALITY STANDARDS

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
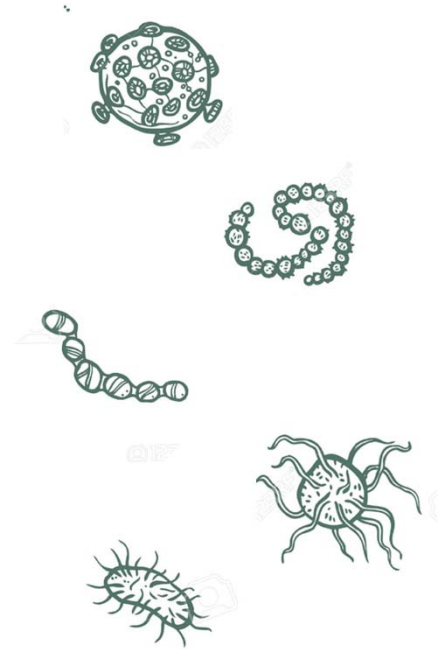
HEALTH RISKS AND WATER QUALITY STANDARDS

Texas Contact Recreation Categories		
PCR	Primary Contact Recreation (PCR)	significant risk of ingestion (swimming, wading by children, tubing, handfishing)
SCR 1	Secondary Contact Recreation 1 (SCR 1)	limited body contact (fishing, kayaking, boating)
SCR 2	Secondary Contact Recreation 2 (SCR 2)	body contact limited due to physical characteristics of water body or limited public access (fishing, kayaking, boating)
NCR	Noncontact Recreation (NCR)	limited body contact often due to unsafe conditions such as barge traffic (hiking, birding)

HEALTH RISKS AND WATER QUALITY STANDARDS

Criteria for Indicator Bacteria in the TCEQ Water Quality Standards

Use Category	E. coli per 100 ml (freshwater)		Enterococci per 100 ml (saltwater)		Enterococci per 100 ml (high saline inland waters)	
	Geo. mean	Derivation	Geo. mean	Derivation	Geo. mean	Derivation
PCR	126	EPA criterion	35	EPA criterion	33	EPA criterion
SCR1	630	5 x PCR	175	5 x PCR	165	5 x PCR
SCR2	1,030	5 x 206 [PCR2]*	---		270	5 x 54 [PCR2]
NCR	2,060	2 x SCR2	350	2 x SCR1	540	2 x SCR2

* 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
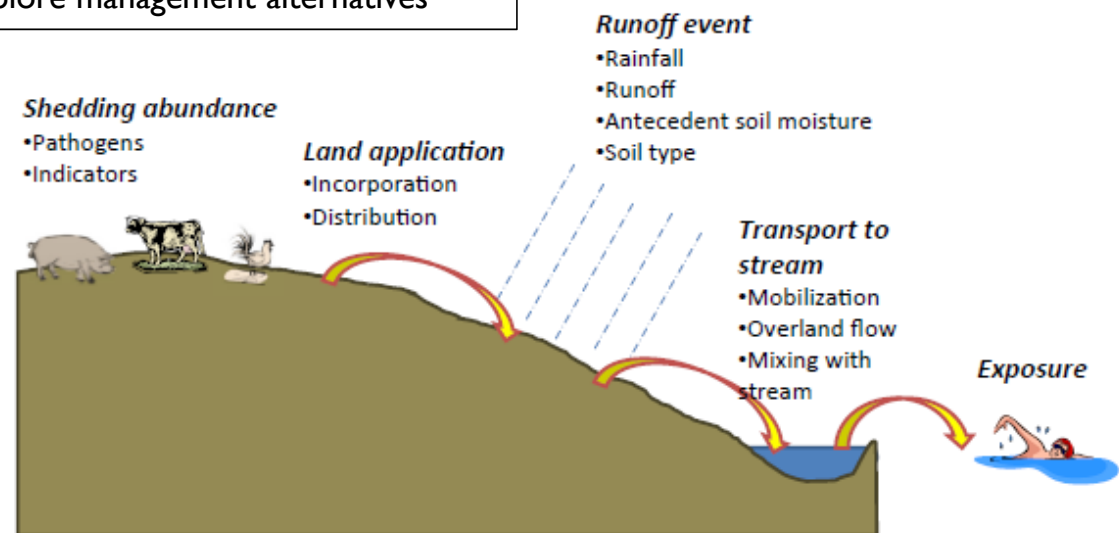 - used by researchers and government to explore management alternatives

Shedding abundance
- Pathogens
- Indicators

Land application
- Incorporation
- Distribution

Runoff event
- Rainfall
- Runoff
- Antecedent soil moisture
- Soil type

Transport to stream
- Mobilization
- Overland flow
- Mixing with stream

Exposure

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

Soller et al. 2015

METHODS DEVELOPMENT AND CURRENT RESEARCH

NON POINT SOURCES OF PATHOGENS

- **Q**uantitative **M**icrobial **R**isk **A**ssessment (**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)
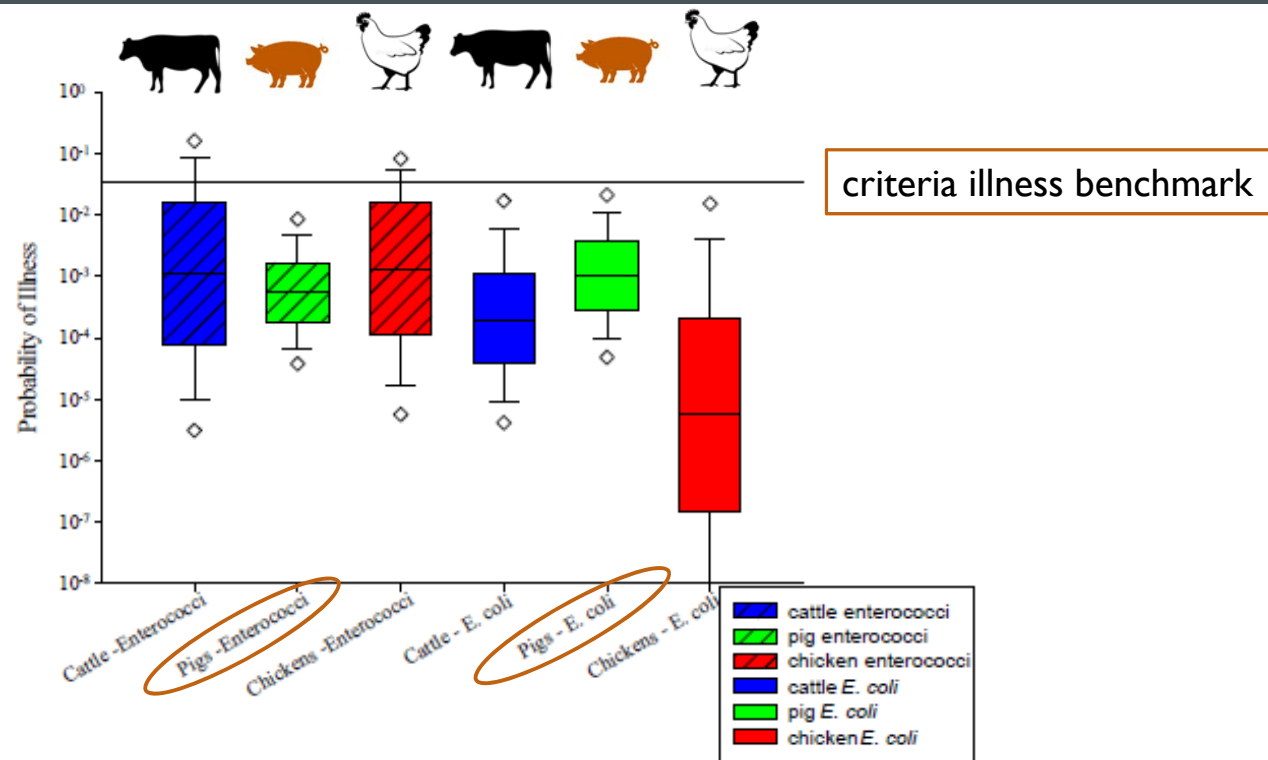
METHODS DEVELOPMENT AND CURRENT RESEARCH

QMRA

Fig. 5. Relative QMRA probability of illness boxplot. Note: edges of box represent 25th and 75th percentiles, diamonds represent 5th and 95th percentiles.

Soller et al. 2015

QMRA

Enterococcus levels associated with illness levels of 36/1000 driven by proportion of human source

Table 2 – Selected predicted median enterococci densities that correspond to GI illness levels of 0.036 for waters impacted by mixed sources of faecal contamination.

Non-human source	Human contribution	0%	10%	20%	30%	50%	70%	100%
	Non-human contribution	100%	90%	80%	70%	50%	30%	0%
Pig		607	278	164	114	70	50	35
Chicken		103	95	87	79	62	49	35
Gull		1947	339	174	116	70	50	35
Non-pathogenic source		—	350	175	117	70	50	35

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Soller et al. 2014

METHODS DEVELOPMENT AND CURRENT RESEARCH

QMRA
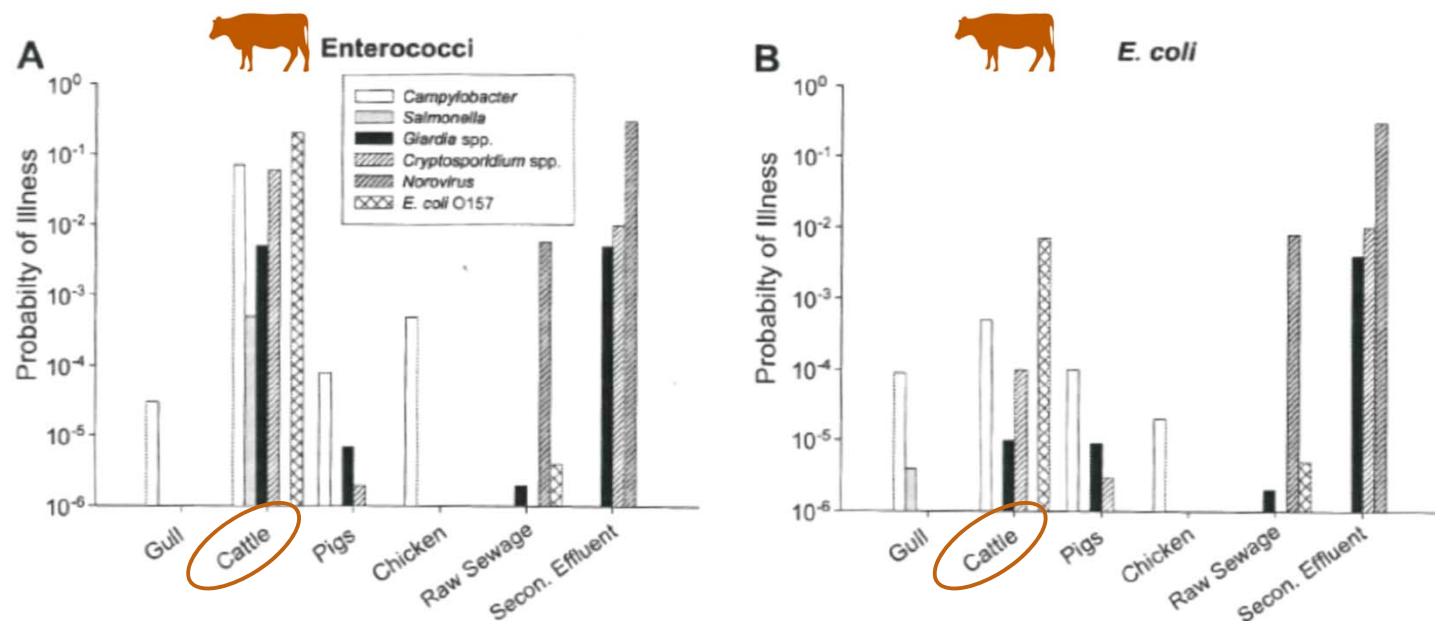
Estimated pathogen contribution from different sources

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).

Soller et al. 2010

METHODS DEVELOPMENT AND CURRENT RESEARCH

QMRA

Exposure to water with direct cattle waste similar to risk from human waste
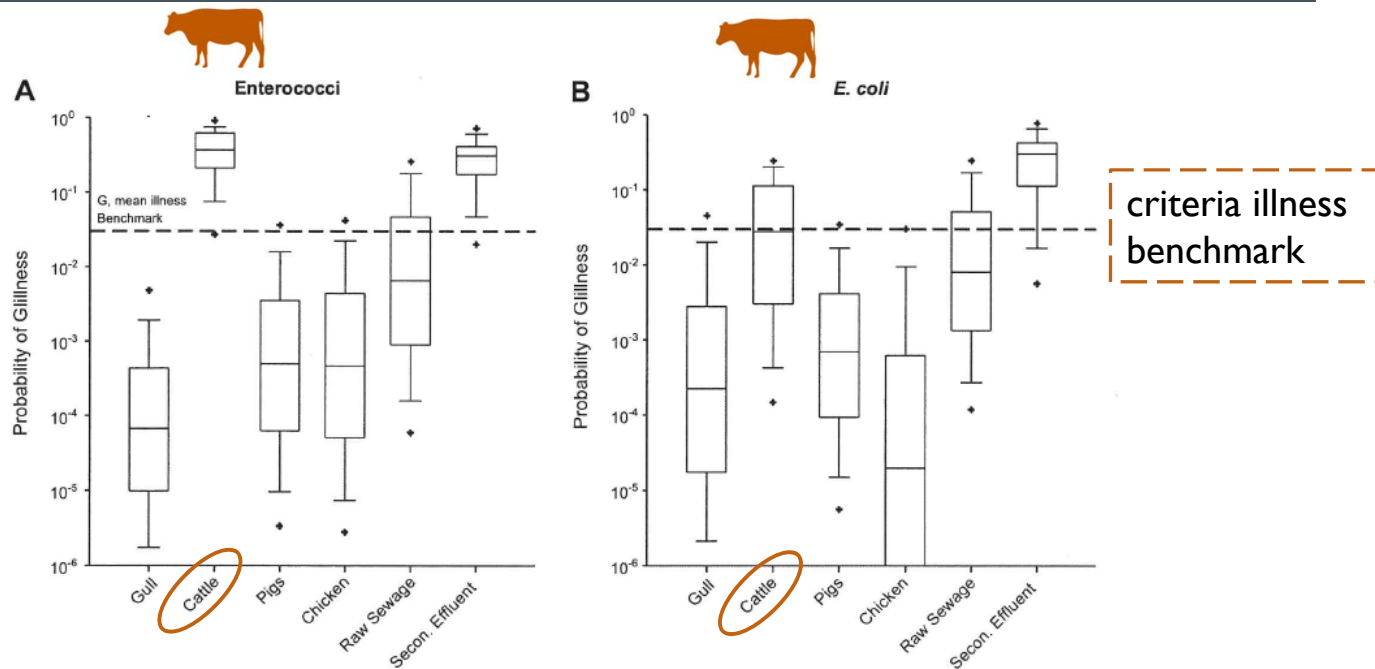
criteria illness benchmark

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} ENT (5A) and 126 cfu 100 mL^{-1} E. coli (5B). 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.

Soller et al. 2010

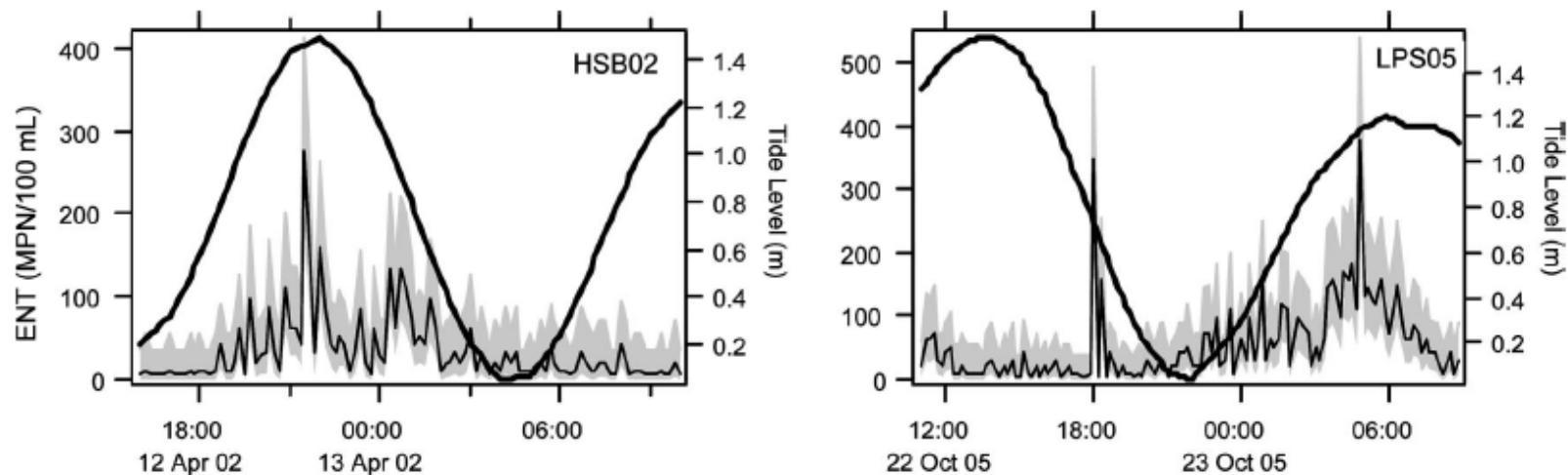*Enterococci* concentrations over 24 hours measured by QPCR

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).

Boehm 2007

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

Structure of bacteriophage

Capsid head
Nucleic acid (DNA)
Collar
Sheath
Baseplate
Spikes
Tail fiber
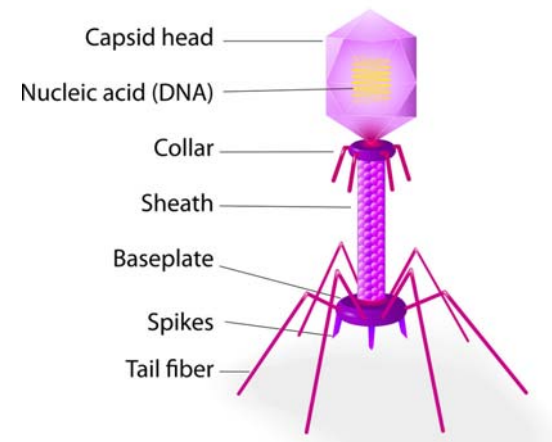
PATHOGENS OF CONCERN

- human enteric viruses – norovirus, rotaviruses, adenoviruses

- *E. coli* O157:H7

- *Giardia lamblia*

- *Cryptosporidium* spp.

- *Campylobacter jejuni*

- *Salmonella enterica*
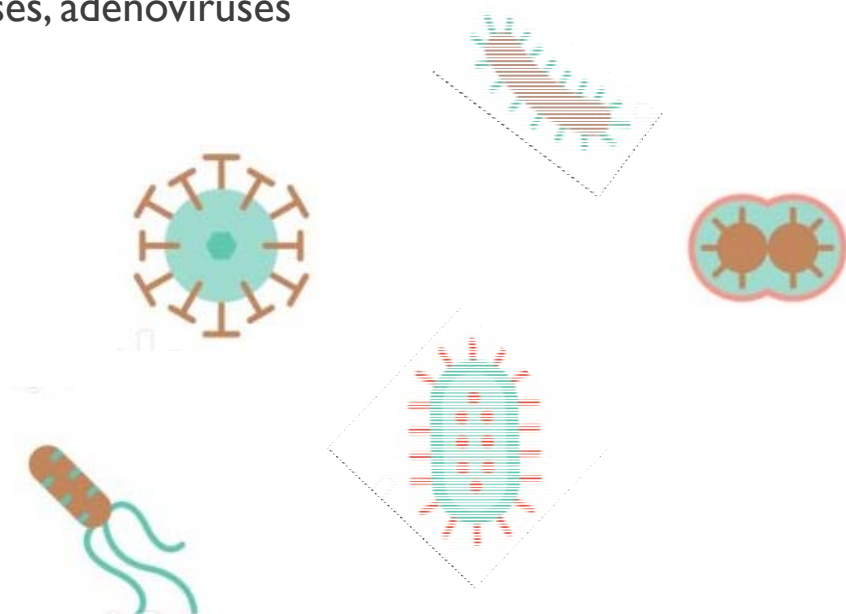
TAKE HOME MESSAGE

- 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

Indicator	Illness rate	Risk level	Geomean
E. coli (FW)	36/1000	3.6%	126 cfu per 100 mL
Enterococcus (SW)	36/1000	3.6%	35 cfu per 100 mL

REFERENCES

Boehm, A.B. 2007. Enterococci Concentrations in Diverse Coastal Environments Exhibit Extreme Variability. Environmental Science and Technology 41(24).

Soller, J.A., Bartrand, T., Ashbolt, N.J., Ravenscroft, J., Wade, T.J., 2010. Estimating the primary etiologic agents in recreational freshwaters impacted by human sources of faecal contamination. Water Res. 44 (16), 4736e4747.

Soller, J.A., Schoen, M.E., Bartrand, T., Ravenscroft, J., Ashbolt, N.J., 2010. Estimated human health risks from exposure to recreational waters impacted by human and nonhuman sources of faecal contamination. Water Res. 44 (16), 4674e4691.

U.S. EPA, 1986. Ambient Water Quality Criteria for Bacteria. EPA440/5-84-002. Office of Water, Washington, DC.

U.S. EPA, 2010. Quantitative Microbial Risk Assessment to Estimate Illness in Freshwater Impacted Agricultural Animal Sources of Fecal Contamination. EPA-R-10e005. Office of Water U.S. Environmental Protection Agency, Washington, D.C.

U.S. EPA, 2012, 820-F-12e058. In: Office of Water (Ed.), Recreational Water Quality Criteria (Washington, D.C).

THANK YOU FOR LISTENING

WHAT QUESTIONS DO YOU HAVE?

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