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ming with the Bugs: Health Risks due to

Swimming with the Bugs: Health Risks due to Recreation along the Wissahickon, Cobbs and Tacony Creeks

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Recreation in natural waterways comes with health risks due to exposure to microbial pathogens.





In 2001 the US EPA estimated 1.8 to 3.5 million people become sick annually due to recreational contact with waters contaminated by sewer overflows.²



"Brianna and Brandon Found Their Favorite Spot in Tacony Creek", Philadelphia by Nadda Abrams

²US EPA. Notice of proposed rulemaking, National pollutant discharge elimination system (NPDES), permit requirements for municipal sanitary sewer collection systems, municipal satellite collection systems, and sanitary sewer overflows. (2001).



In 2018, the US EPA estimated that 90 million illnesses across the US are attributable to recreation in surface waters, which costs and estimated \$2.2-\$3.7 billon annually

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Environmental Health

RESEARCH



Open Access

Estimate of incidence and cost of recreational waterborne illness on United States surface waters

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Acute Gastrointestinal Illness (AGI):

Definition : three or more loose stools in 24 hours or any vomiting excluding those with chronic conditions or concurrent symptoms of coughing, sneezing, sore throat or runny nose.





Defining Recreation

Primary Recreation

Definition: Direct contact with water where immersion and ingestion are likely



Summary of Recreational Waterborne Disease Studies



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**Courtesy of Henry Ngo, University of Guelph



How can we measure/ estimate health risks?



Randomized controlled trials

Prospective Cohort studies

2. Quantitative Microbial Risk Assessment (QMRA)

Randomized Controlled Trials (RCTs)



- The "gold standard" of epidemiological studies
 - Comparison of illness rates between two randomly chosen groups:
 - Control participants don't swim
 - Intervention participants swim
- Participants are randomly assigned the intervention
- 2 RCTs have been conducted to date in recreational setting (Florida, UK)
- RCT are challenging to use in this context



Fig. 3 A double-blind placebo-controlled clinical trial for CAM therapies.

Prospective Cohort Studies



- Executed in a similar way as the RCT
- Participants recruited at the beach
- Participants followed no matter what their exposure (not assigned to swimming or not swimming)
- Participants called 8-14 days after beach exposure
- 11 studies from US, Canada, UK, Spain
- Both RCTs and Cohort studies are costly and time consuming



Quantitative Microbial Risk Assessment (QMRA)



- Pathogen specific
- Result is a risk of illness or infection
 - Acceptable risk is \sim 36 in 1000 exposures (3.6%)



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Study Background

- Recreation along waters impacted by combined sewer overflows (CSOs) in Philadelphia can represent a health risk
- Research is lacking around the potential health risks due to recreation along the Wissahickon



Combined Sewer Overflow, 2017, Philadelphia Water Department http://www.phillywatersheds.org/watershed_issues/stormwater_management/combined_sewer_system

Sources of Fecal Pollution in Study Area











- What is the risk of illness due to recreational activities observed at sites along the Wissahickon Creek?
- 2. How does this compare to the risk calculated due to recreation along CSO-impacted sites in Philadelphia?



https://www.phillymag.com/news/2015/07/26/devils-pool-philadelphia/



1. Fecal indicator organism (FIO) data from grab samples at sites along Wissahickon, Cobbs and Tacony Creeks

2. Pathogen data collected through ultrafiltration (UF) and analyzed by qPCR

3. QMRA models for selected pathogens to estimate health risks of recreating in these waterways



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0 0.41 0.82 1.64 Miles

Surface Water Sampling Sites, 2016 - 2020















Sample Collected

• Samples (N=70) were collected May 2020-September 2020:

Site	Wet (n =)	Dry (n =)	Total (n =)
Devil's Pool (W-DP)	3	7	10
Rope Swing (W-RS)	3	7	10
Kitchens Lane (W-KL)	3	7	10
Valley Green Inn (W-VG)	3	7	10
Margaree Dam (W-MD)	3	7	10
Cobbs Creek (CB)*	2	8	10
Tacony Creek (TC)*	3	7	10
* 10 samples for CB (5) & TC (5) were pulled from			
archived samples from 2018 & 2019	70		

- 1L grab samples for *E*. coli, total coliforms, fecal enterococci, and fecal (thermotolerant) coliforms
- ~ 50L were filtered using dead-end ultrafiltration to measure for human sewage markers and enteric pathogens
- Wet/dry samples collected



Fecal Indicator Organisms: Methods

What are fecal indicator organisms?

- Indicators of fecal contamination in water
- Commonly used indicators are bacteria:
 - Total Coliforms (TC)
 - Thermotolerant/ Fecal Coliforms (FC)
 - E.coli
 - Enteroccoci
- Recreational water guidelines are based on these indicators











Table 1. Recon	nmended 2012 R	WQC.					
	Estimated Illn	ess Rate (NGI):		Estimated III	ness Rate (NGI):		
0.11.1	36 per 1,000 primary contact			32 per 1,000	primary contact		
Criteria	recreators			recreators			
Elements	wiagi	nitude		Ma	gnitude		
	GM	STV		GM	STV		
Indicator	$(cfu/100 mL)^{a}$ $(cfu/100 mL)^{a}$		OR	$(cfu/100 mL)^{a}$	(cfu/100 mL) ^a		
Enterococci							
- marine							
and fresh	35 130			30	110		
OR							
E. coli							
– fresh	126 410 100 320						
Duration an	Duration and Frequency: The waterbody GM should not be greater than the selected GM						
magnitude in any 30-day interval. There should not be greater than a ten percent excursion							
frequency of the selected STV magnitude in the same 30-day interval.							

PA also uses a GM of 200 cfu/ 100mL for fecal coliforms

*Note: We did not sample per EPA guidelines, we are using these as a frame of reference

Methods: FIOs



Membrane Filtration







Indicators Results



 Values shown in red indicate a geometric mean/ STV higher than the EPA/PA guidelines

		Geo	ometric N	lean (cfu/100r	STV % Exceedance (cfu/100m)			
Site	n	Total Coliforms	E. coli	Enterococci	Fecal Coliforms	E.coli	Enterococci	Fecal Coliforms
W-RS	10	120,103	614	37	779	40%	30%	70%
W-DP	10	50,354	30	11	158	20%	10%	30%
W-KL	10	75,814	357	32	1071	40%	10%	80%
W-MD	10	64,356	258	10	359	20%	10%	40%
W-VG	10	78,531	355	25	455	40%	20%	60%
Total	50	74,644	227	20	464	32%	16%	56%

US EPA's guidelines for primary recreation:

- *E. coli GM* (126 cfu/100 mL); STV (410 cfu/100mL)
- Enterococci (35 cfu/100 mL); STV (130 cfu/100mL)

PA guidelines for primary recreation

 Fecal Coliforms (200 cfu/ 100mL)I STV (400/100mL)

Wissahickon Results: FIOs



 Values shown in red indicate statistically significantly higher geometric mean of the indicator in the rain sample

		D	ry		Rain			
Site	Total Coliforms	E. coli	Enterococci	Fecal Coliforms	Total Coliforms	E. coli	Enterococci	Fecal Coliforms
	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)
W-DP	41,217	8	5	63	80,339	<u>596</u>	<u>88</u>	<u>1,356</u>
W-RS	56,838	<u>217</u>	7	181	688,160	<u>6968</u>	<u>1,615</u>	<u>23,553</u>
W-VG	66,062	<u>375</u>	22	<u>252</u>	117,562	<u>314</u>	<u>37</u>	<u>1,810</u>
W-MD	55,374	<u>190</u>	6	172	91,397	<u>524</u>	25	<u>1,985</u>
W-KL	74,178	<u>239</u>	19	<u>812</u>	79,773	<u>908</u>	<u>114</u>	<u>2,043</u>

US EPA's guidelines for primary recreation:

- *E. coli GM* (126 cfu/100 mL); STV (410 cfu/100mL)
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PA guidelines for primary recreation

 Fecal Coliforms (200 cfu/ 100mL)I STV (400/100mL)

Takeaways from FIO Results: Wissahickon





- Dry samples exceeded guidelines for *E.coli* at most sites
- Wet samples exceeded guidelines for nearly all sites and FIOs
- In dry conditions, *enterococci* guideline less likely to be exceeded
- **Devil's Pool** and **Rope Swing** showed the greatest increases in FIO markers after rainfall events.
- Recreation within 24 hours of rainfall could be riskier than during dry conditions

https://www.phillymag.com/news/2015/07/26/devils-pool-philadelphia/

CSO Results: FIO Markers



 Values shown in red indicate a geometric mean/ STV higher than the EPA/PA guidelines

		G	eometric M	ean (cfu/100m	STV % Exceedance (cfu/100mL)			
Site	n	Total Coliforms	E. coli	Enterococci	Fecal Coliforms	E.coli	Enterococci	Fecal Coliforms
СВ	10	158,671	4,462	144	4,257	70%	20%	100%
тс	10	282,908	11,269	1016	38,558	100%	60%	100%
Total	20	222,962	7,695	382	12,812	88%	40%	100%

US EPA's guidelines for primary recreation:

- E. coli GM (126 cfu/100 mL); STV (410 cfu/100mL)
- Enterococci (35 cfu/100 mL); STV (130 cfu/100mL)

PA guidelines for primary recreation

 Fecal Coliforms (200 cfu/ 100mL)I STV (400/100mL)

CSO Results: FIO Markers



 Values shown in red indicate statistically significantly higher geometric mean of the indicator in the rain sample

		D)ry		Rain			
Site	Total Coliforms	E. coli	Enterococci	Fecal Coliforms	Total Coliforms	E. coli	Enterococci	Fecal Coliforms
	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)	(cfu/100mL)
тс	232,211	<u>15,730</u>	<u>1,016</u>	<u>38,558</u>	365,267	<u>7,686</u>	-	-
СВ	125,469	<u>3,354</u>	<u>63</u>	<u>1,739</u>	643,614	<u>17,269</u>	<u>3,950</u>	<u>153,000</u>

US EPA's guidelines for primary recreation:

- E. coli GM (126 cfu/100 mL); STV (410 cfu/100mL)
- PA guidelines for primary recreation
- Fecal Coliforms (200 cfu/ 100mL)
- Enterococci (35 cfu/100 mL); STV (130 cfu/100mL)

Please Note:

- Data was aggregated from Summer 2018 Summer 2020 (5 out of 10 samples came from 2020, the rest from Summer 2018 and 2019)
- Enterococci and Fecal Coliforms were only tested for in Summer 2020
 - No wet samples were collected in 2020 at TC

Takeaways from FIO Results: CSOs





- 5/ 6 wet samples had greater FIO geometric means dry samples
- Even without rain, all FIOs were above recreational guidelines.
- Recreation following rain may be riskier than during dry conditions.



Pathogens: Methods

What pathogens are found in surface water ? College of Public









Viruses norovirus

- Extremely small
- Infectious
- Often move like chemicals

Bacteria Salmonella, Campylobacter

- Microscopic (smaller than algae)
- *E.coli/* coliforms are bacteria

Protozoa

Cryptosporidium, Giardia

- Size of algae
- Produce egg like cysts
- Resistant to chlorine

Routes of Infection?



Ingestion/Inhalation (e.g. drinking water, bathing, recreation, hand to mouth, food)



Viruses



Bacteria Salmonella, Campylobacter



Protozoa Cryptosporidium, Giardia



Indicators	Pathogens
- Mostly bacteria	-Viruses, bacteria, protozoa
- Present in larger quantities	-Present in lower quantities
in feces and/or the	-Challenging to measure
environment	-More costly to monitor
- Easier to detect/ measure	- <u>Can be directly linked to</u>
- Less costly to monitor	<u>health risk</u>
- Indirectly can suggest a	
health risk	

Total coliforms, fecal coliforms and *E.coli* belong to the bacteria group and don't behave like viruses or protozoa

Methods: Pathogens



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Ultrafiltration






Methods: Pathogens

• Ultrafilters sent to USDA/USGS lab, for qPCR or RT-qPCR:



Human pathogens:

Methods: Pathogens

- Viruses
 - adenovirus, enterovirus, norovirus GI & GII, SARS-CoV-2, Hepatitis A, rotavirus
- Bacteria
 - Campylobacter, enterohemorrhagic E. coli, Salmonella, Shigella
- Protozoa
 - Giardia, Cryptosporidium







Image: norovirus; cdc.org



Methods: Human Sewage Markers



- Genetic markers of human sewage
 - Human Bacteroides (HF183)
 - Pepper mild mottle virus
 - Human polyomavirus





Pathogen Results

Virus Results: Wissahickon





adenovirus- detected in 13% of samples (9/70)



enterovirus- not detected



SARS-CoV-2- not detected



norovirus (GI,GII)- detected in 1.4% samples (1/70)



Hepatitis A- not detected



rotavirus- detected in 67% of samples (47/70 samples)





Campylobacter- detected in 1.4% of samples (1/70)



Salmonella spp.- detected in 5.7% of samples (4/70)



Enterohemorrhagic and Shiga-toxin producing E.coli and Shigelladetected in 7.1% of samples (5/70)



Cryptosporidium spp.- detected in 40% of samples (28/70)



Giardia- detected in 1.4% of samples (1/70)

Wissahickon Results: Pathogens





70% of samples tested positive for 1 pathogen

40% of samples tested positive for 1-2 pathogens



Wissahickon Results: Pathogens

80% of samples tested positive for 1-3 pathogens

80% of samples tested positive for 1-2 pathogens



Wissahickon Results: Pathogens





90% of samples tested positive for 1-2 pathogens



Virus Results: CSOs



adenovirus- detected in 55% of samples (11/20)



enterovirus- detected in 15% of samples (3/20)



SARS-CoV-2- not detected



norovirus (GI,GII)- detected in 30% samples (6/20)



Hepatitis A- not detected



rotavirus- detected in 80% of samples (16/20 samples)





Campylobacter- detected in 15% of samples (3/20)



Salmonella spp.- detected in 30% of samples (6/20)



Enterohemorrhagic and Shiga-toxin producing E.coli and Shigelladetected in 50% of samples (10/20)



Cryptosporidium spp.- detected in 65% of samples (13/20)



Giardia- detected in 20% of samples (4/20)

Between 1-4 pathogens detected in all samples collected on the CSO sites

CSO Results: Pathogens





100% of samples tested positive for 1- 4 pathogens



100% of samples tested positive for1- 6 pathogens



<u>Human specific fecal markers</u> were detected at <u>all sites</u> <u>nearly 100%</u> of the time.

Levels reached concentrations that can be found in dilute sewage.



BREAK



Translating pathogen and sewage marker data into recreational risk assessment



Quantitative Microbial Risk Assessment (QMRA)



 Modeling approach to estimate the risk of illness (or infection) after exposure to microorganisms in the environment





Two modelling approaches employed:

1. Used measured human sewage marker (HF183) data to calculate illness risk

2. Used measured pathogen data to calculate illness risk

Hazard Identification

Pathogens: norovirus, adenovirus, enterovirus, Giardia, Cryptosporidium, E.coli O157:H7, Salmonella, Campylobacter



HF183 to estimate pathogens

- What is HF183?- Human Bacteroides- bacteria specific to the human gut and therefore representative of human fecal material
- Author measured pathogens and HF183 markers at 54 US locations
- We used their work to estimate pathogens in our samples from our HF183 measurements





pubs.acs.org/journal/estlcu

Human-Associated Fecal Quantitative Polymerase Chain Reaction Measurements and Simulated Risk of Gastrointestinal Illness in Recreational Waters Contaminated with Raw Sewage

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Supporting Information



<u>Pathogens in sewage</u> x HF183 in samples = Pathogens in samples (per L) HF183 in sewage







Concentrations of pathogens were included in the model as follows:

1. We looked at how many samples were positive for that given pathogen and calculated the likelihood that the pathogen was present

2. If a sample was positive, probability distributions using the raw data were used to estimate pathogen concentration.





Quantitative Microbial Risk Assessment (QMRA)





Exposure Assessment





Exposure Pathways



Exposure Assessment

Volume of water ingested =

Ingestion rate per activity (mL/hr) x duration of activity (hr)

Dosage of pathogens ingested =

Volume of water ingested (mL) x concentration of pathogens (organisms/mL)





Quantitative Microbial Risk Assessment (QMRA)





Dose-Response

- Curves from feeding studies, outbreak data
- Selection was on:
 - Study methods
 - Sample size
 - Use in previous QMRAs
- For norovirus and Campylobacter, used 2 curves







- Four risk models developed per exposure:
 - norovirus Model 1; Campylobacter Model 1
 - norovirus Model 1; Campylobacter Model 2
 - norovirus Model 2; Campylobacter Model 1
 - norovirus Model 2; Campylobacter Model 2
- Results presented for two models: the most and least cautious combinations

Quantitative Microbial Risk Assessment (QMRA)





Results: Wissahickon Sites





Results: Devil's Pool





US EPA's guidelines for primary recreation:

- *E. coli GM* (126 cfu/100 mL); STV (410 cfu/100mL)
- Enterococci (35 cfu/100 mL); STV (130 cfu/100mL)

PA guidelines for primary recreation

Fecal Coliforms (200 cfu/ 100mL)I STV (400/100mL)

Results: CSO sites





Enterococci (35 cfu/100 mL); STV (130 cfu/100mL

Fecal Coliforms (200 cfu/ 100mL)I STV (400/100mL)

Pathogen Estimates vs. HF183 Estimates





Least Cautious Pathogen Estimate



Cautious HF183 Estimate



Least Cautious HF183 Estimate



Results



Pathogen model

- Illness risk higher than EPA acceptable risk in CSO impacted waterways for all activities
- Not the case for Devil's Pool or Wissahickon



HF183 model

 All sites showed higher mean illness than EPA acceptable risk in CSO impacted waterways and Devil's Pool for all activities (Swimming, Wading, & Fishing)



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- HF183 model more appropriate for waterways with CSOs or known human sewage
- FIOs guidelines for primary recreation did not align with pathogen risk estimates
 - Thermotolerant coliforms (fecal coliforms) and *E.coli* results suggest that you should not swim in the Wissahickon or Devil's pool
- Pathogen risk model suggest mean risk is between:
 - 0.5-1.5 cases/ 1000 swimmers for Wissahickon
 - 1.5 cases/ 1000 swimmers for Devil's Pool

Study Strengths & Limitations



STRENGTHS

- Study sites representative of recreational activities
- Many sites
- Analyzed for many pathogens
- Collected 10 samples per site over swimming season
- Multiple models (dose response & exposure assessment)

LIMITATIONS

- No culture data
- Only 1 summer pathogen data
- Recreational behaviours may have been affected by COVID
- Few rain events
- Rotavirus not included
- Combined Tacony and Cobbs data as well as wet and dry weather data due to limited samples

Quantitative Microbial Risk Assessment (QMRA)






- 1. Wet weather may be riskier than dry weather
- 2. Indicator organisms do not correlate with pathogen presence (and certain indicators may overestimate the health risk)

-Enteroccocci seems to be a better indicator

- 3. HF183 QMRA model can be used to estimate illness risk in sewage impacted waters; not appropriate for non-impacted
- 4. Even though risk was low, there were still pathogens found in the Wissahickon
- Human recreators likely contributing to contamination in Wissahickon (rotavirus & HF183 results)



Tacony & Cobbs Creeks

- All recreation is risky
- No swimming, wading
- Fishing only if appropriate hand hygiene is promoted





Wissahickon

- Wading and fishing low risk
- Swimming poses higher risk (although on average lower than EPA acceptable risk)





Devil's Pool

- Wading and fishing low risk
- Swimming poses higher risk than Wissahickon (although on average lower than EPA acceptable risk)



Future Work-Recommendations



- Microbial source tracking for the Wissahickon
- Identify pathogen sources, particularly for dry weather
- Investigation of sources of pollution (leaking septic or stormwater drains)
- Investigate upstream influences



Thomas, J.L. (2017). Microbial Source Tracking to Identify Fecal Pollution Sources in Water.





Future Work- Recommendations



- Increase sampling FIB in accordance with the EPA/ PA guidelines to better characterize water quality
 - Focus on enterococci
- Develop individual site and specific event risk estimates (ie. weather conditions, months, temperatures)



Recommendations- Public Health





- Recreation should not occur in CSO waters
- Risk is likely higher for children, elderly and immunocompromised
- Messaging about the risks need to be more clearly communicated/ strategies developed
- Trash and bathroom facilities needed to avoid human fecal contamination



How can we help you and other stakeholders utilize these results?





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The Academy of Natural Sciences





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