BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
WATER QUALITY STANDARDS AND	)	R08-9
EFFLUENT LIMITATIONS FOR THE	)	(Rulemaking - Water)
CHICAGO AREA WATERWAY SYSTEM	)	
AND THE LOWER DES PLAINES RIVER:	)	Subdocket B
PROPOSED AMENDMENTS TO 35 Ill.	)	
Adm. Code Parts 301, 302, 303 and 304	)	

NOTICE OF FILING

To: ALL COUNSEL OF RECORD
(Service List Attached)

PLEASE TAKE NOTICE that on the 6th day of December, 2010, I, on behalf of the Metropolitan Water Reclamation District of Greater Chicago, electronically filed “The Chicago Health, Environmental Exposure, and Recreation Study (CHEERS) Supplement,” with the Office of the Clerk of the Illinois Pollution Control Board.

Dated: December 6, 2010

METROPOLITAN WATER RECLAMATION DISTRICT OF GREATER CHICAGO

By: */s/ Fredric P. Andes*
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PROOF OF SERVICE

The undersigned, a non-attorney, certifies, under penalties of perjury pursuant to 735 ILCS 5/1-109, that I caused a copy of the forgoing, **Notice of Filing** and **The Chicago Health, Environmental Exposure, and Recreation Study (CHEERS) Supplement,** to be served via First Class Mail, postage prepaid, from One North Wacker Drive, Chicago, Illinois, on the 6th day of December, 2010, upon the attorneys of record on the attached Service List.

/s/ Barbara E. Szynalik
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The Chicago Health, Environmental Exposure, and Recreation Study (CHEERS)

Supplement

Prepared by
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December 6, 2010

CHEERS
WATER CHICAGO SPORTS

UIC UNIVERSITY OF ILLINOIS AT CHICAGO SCHOOL OF PUBLIC HEALTH

ABSTRACT

The Chicago Health, Environmental Exposure, and Recreation Study (CHEERS) evaluated the health risks of limited contact water recreation activities - motor boating, canoeing, fishing, kayaking, and rowing – on the Chicago Area Waterways System (CAWS). The CAWS receives treated, but non-disinfected, wastewater from water reclamation plants of the Metropolitan Water Reclamation District of Greater Chicago, the funder of CHEERS. CHEERS was designed using the methods of USEPA studies of water recreation and health. In addition to enrolling participants at CAWS locations, a comparison group was recruited at area inland lakes, rivers, and Lake Michigan. A second comparison group consisted of people who participated in recreation activities such as jogging and cycling, which do not involve water.

A variety of bacteria, viruses, and parasites that can cause human disease were measured in the water. Generally, levels of these bacteria and parasites were much higher at CAWS locations than at other waters. For most of these microbes, levels were higher downstream of the water reclamation plants compared to upstream of the plants. Some of the microbes were found at high levels at non-CAWS rivers and at inland lakes.

During the water recreation seasons of 2007-2009, 11,297 individuals participated in the CHEERS study and provided telephone follow-up information. Figure 1 summarizes the types and frequency (the best estimate and the 95% confidence interval) of illness attributable to limited contact recreational activities on the CAWS, with non-water recreation as the reference category. If the confidence interval for a type of illness is entirely above 0, that means that CAWS users have a higher risk of developing that type of illness than the non-water recreators. The number next to the confidence interval is the best estimate of number of excess cases that we would expect in the CAWS group compared to the non-water group. This shows that if 1,000 people used the CAWS and 1,000 people did non-water recreation, about 12-13 more cases of acute gastrointestinal illness and 15-16 more cases of eye symptoms would occur among CAWS users. This takes into account demographic and other differences among the study groups. There were no differences among groups in the risk of acute respiratory illness, skin rash, or acute ear symptoms.

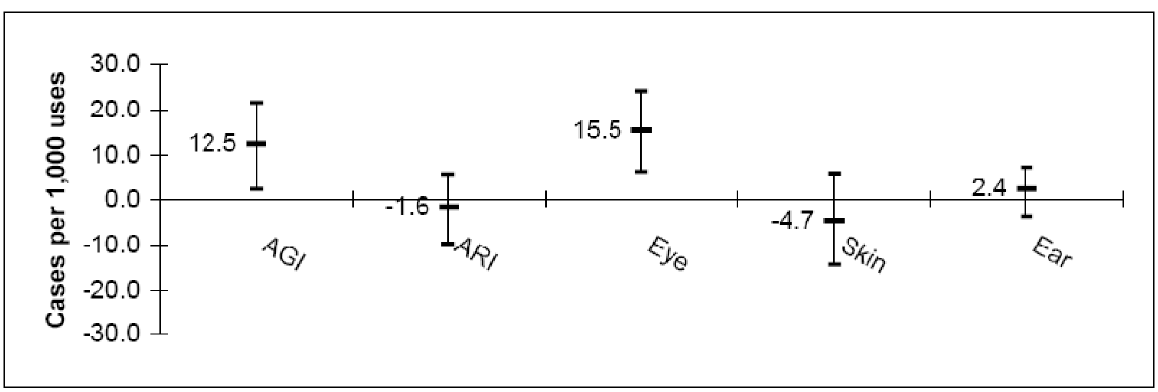

Figure 1: Cases attributable to CAWS recreation, with non-water recreation as the reference group. AGI= acute gastrointestinal illness. ARI=acute respiratory illness.

Figure 2 summarizes the types and frequency of illness attributable to limited contact recreational activities on general use waters, with non-water recreation as the reference category. This shows that if 1,000 people used general use waters and 1,000 people did non-water recreation, about 13-14 more cases of acute gastrointestinal symptoms would occur among general use waters users. This takes into account demographic and other differences among the study groups. There were no differences between groups in the risk of acute respiratory illness, eye symptoms, or acute ear symptoms. Skin rash was less common among users of general use waters than among non-water recreators.

General use waters vs. non-water recreators:

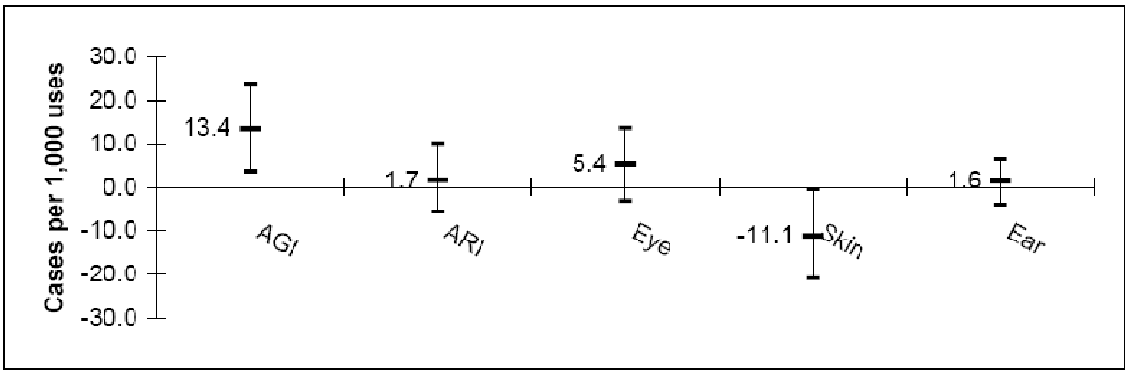

Figure 2: Cases attributable to general use water recreation, with non-water recreation as the reference group. AGI=acute gastrointestinal illness. ARI=acute respiratory illness.

Figure 3 summarizes the types and frequency of illness attributable to limited contact recreational activities on the CAWS, with limited contact recreation on general use waters as the reference category. This shows that if 1,000 people used the CAWS and 1,000 people used general use waters for these same activities, about 11 more cases of eye symptoms would occur among CAWS users. This takes into account demographic, water exposure, and other differences among the study groups. There were no statistically signficant differences between groups in the risk of gastrointestinal illness, acute respiratory illness, skin rash, or acute ear symptoms.

CAWS vs. general use water recreators:

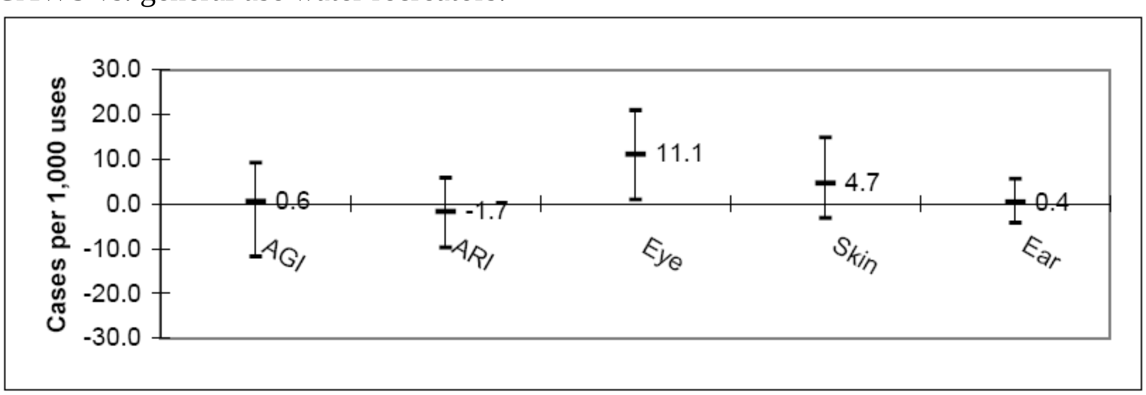

Figure 3: Cases attributable to CAWS recreation, with general use water recreation as the reference group. AGI= acute gastrointestinal illness. ARI=acute respiratory illness.

The severity of gastrointestinal illness was comparable among the three study groups. About one third of study participants who developed symptoms of gastrointestinal illness provided stool samples for analysis. For all three groups of study participants, microbes responsible for illness (pathogens) were detected in about 10% of the cases. The type of microbe most commonly found in stool samples was viruses. Microbes that generally cause severe illness were not detected in any of the stool samples.

Among CAWS recreators, no relationship between microbe concentration and gastrointestinal illness was apparent. Of the six microbes measured during water recreation, only concentrations of enterococci were associated with an increased risk of developing acute gastrointestinal illness among recreators on general use waters. The association was limited to those recreators with signficant water exposure. On the CAWS, the occurrence of combined sewer overflows in the 24 hours prior to recreation was also associated with a four-fold increase in risk of AGI. No associations were apparent between bacterial indicators and the other health endpoints for CAWS recreators.

In summary, gastrointestinal illness attributable to motor boating, canoeing, fishing, kayaking, and rowing, occurred at a rate of about 12 cases per 1,000 uses of the CAWS. This risk is comparable to that seen among those who do the same activities on general use waters. Pathogens that generally cause severe illness were not detected in stool samples. Eye symptoms due to CAWS recreation occurred at a rate of 15.5 cases per 1,000 uses. The eye symptoms were mild, but did occur more frequently among CAWS users than among limited contact recreation users of general use waters. The health risks of CAWS recreation appeared to be comparable to the health risks of limited contact water recreation at area rivers, inland lakes, or Lake Michigan, with the exception of somewhat more frequent eye symptoms, which were mild, following CAWS recreation. Continued improvements in storm water management on the CAWS and reductions in water exposure on the CAWS and general use waters should results in lower rates of acute gastrointestinal illness.

Executive Summary

Background

The Chicago Area Waterways System (CAWS) is a 78-mile-long, primarily man-made series of channels and rivers. It is partly natural but has been irreversibly modified. The CAWS includes the North Shore Channel, the North and South Branches of the Chicago River, the Main Stem of the Chicago River, the South Fork of the Chicago River (Bubbly Creek), the Chicago Sanitary and Ship Canal, the Cal-Sag Channel, the Calumet River, portions of the Little Calumet River, the Grand Calumet River, and Lake Calumet. The primary purposes of the system are transportation, commerce, and to provide an outlet for urban drainage and treated municipal wastewater in order to protect Lake Michigan, the source of drinking water for Chicago and nearby communities. In recent decades, with improvements in CAWS water quality, recreation on the CAWS has become popular. Four water reclamation plants of the Metropolitan Water Reclamation District of Greater Chicago release treated, but non-disinfected, wastewater effluent into the CAWS. It has been estimated that 70% of the annual flow in the system is effluent from the water reclamation plants, and during dry weather, effluent accounts for a higher percent of all flow. Storm runoff and combined sewer overflows during and immediately after significant rainfall introduce water and contaminants into the CAWS. In addition to water reclamation plants and precipitation, the North Branch (also referred to as the Northwest Branch), which provides drainage for a forest preserve system, flows into the CAWS at the North Branch Dam. The Main Stem of the Chicago River receives limited flow from Lake Michigan.

The Illinois Pollution Control Board establishes use designations for Illinois surface waters. With a few exceptions, most of the CAWS is designated Secondary Contact Recreation and Limited Aquatic Life. This designation allows recreational activities during which water contact is incidental or accidental and for which the probability of ingesting appreciable quantities of water is minimal, including canoeing, kayaking, and fishing, but not jet skiing or swimming. The secondary contract use designation is not associated with a microbial water quality standard.

Because of water quality improvements in recent years, the Illinois Environmental Protection Agency has recommended a use upgrade for parts of the CAWS that are currently designated Secondary Contact Recreation and Limited Aquatic Life. These improvements stem from efforts by the State of Illinois to meet the goal of the Clean Water Act to make all bodies of water "fishable and swimmable," wherever attainable. The Illinois Environmental Protection Agency has proposed new use designations for regions of the CAWS: 1) non-recreational use, 2) non-contact recreation, and 3) incidental contact recreation, which would include small craft motor boating and any limited contact associated with shoreline activity such as wading. The Illinois Environmental Protection Agency has also proposed a limit on the level of bacteria in wastewater released into portions of the CAWS where water contact recreation takes place. Achieving that limit would require disinfection of wastewater at water reclamation plants that discharge into the CAWS.

Executive Summary

In order to characterize the health risks of CAWS recreation under current (that is, non-disinfection) conditions, on April 19, 2007 the MWRDGC Board of Commissioners voted to establish a contract with the University of Illinois at Chicago (UIC), which would conduct an epidemiologic study of recreational use of the CAWS. That study is CHEERS, the Chicago Health, Environmental Exposure, and Recreation Study. Specific aims of CHEERS were:

1) To determine rates of acute gastrointestinal and non-gastrointestinal illness attributable to CAWS recreation.

2) To characterize the relationship between concentrations of microbes in the CAWS and rates of illness among recreators.

3) To identify pathogens responsible for symptoms of acute gastrointestinal illness among recreators and to explore sources of those pathogens in the CAWS.

Study objective #1 has been met. The methods used to meet this objective are summarized in Chapter IV, while the results are presented in detail in Chapters V through IX. Study objective #2 has been met; the methods and results are summarized in Chapter XI. Study objective #3 has been met; the results are presented in Chapter X.

The purpose of this study was not to develop regulatory standards, but the findings of this research may provide a scientific basis for the development of state or federal water quality standards. The study utilizes the prospective cohort design, the approach used by epidemiologic studies of swimming at beaches conducted by the USEPA. Three groups of participants were enrolled in CHEERS: 1) CAWS recreators (the “CAWS group”), 2) recreators on Lake Michigan and other general use waters (the “general use group”), and 3) outdoor recreators with no water exposure, such as joggers and cyclists (the “unexposed group”). CAWS and general use recreators engaged in motor boating, canoeing, kayaking, fishing, and rowing. People who intended to swim were not enrolled in the study, though study participants who fell into the water (for example, after a kayak capsized) and swam remained eligible to complete the study.

The design of this research underwent an external peer review committee of nationally recognized experts in the field. The peer review committee has continued to monitor study progress, data quality, data analyses, and the development of this report.

Additional information about the background of this research can be found in Chapter I of this report.

Executive Summary

Water quality
The primary measures of microbial water quality in CHEERS were: the indicator bacteria *E. coli* and enterococci, the indicator viruses somatic and male-specific coliphage, and the protozoan pathogens *Cryptosporidium* and *Giardia*. At locations where recreation began and ended at the same point (generally boat launches, piers, and beaches), water was sampled for indicator analyses once every two hours, and once every six hours for pathogen analyses. At CAWS locations, water was sampled upstream and downstream of the nearest upstream water reclamation plant during the time of recreation. In addition to protozoan pathogens, viral pathogens (adenovirus, norovirus and enterovirus) were measured in selected samples in 2009.

Indicator Bacteria
Concentrations of the indicator bacteria, *E. coli* and enterococci, were generally higher at CAWS locations than at general use waters locations. An exception was the density of enterococci at general uses rivers, which was similar to the density in CAWS. Within general use waters, indicator bacteria concentrations were lowest at Lake Michigan harbors.

Within CAWS, the concentrations of *E. coli* and enterococci were higher in the North and South Branch than in the Cal-Sag Channel. They were also higher downstream of the North Side and Calumet Water Reclamation Plants compared to upstream locations.

Indicator Viruses
Concentrations of the coliphage indicator viruses were about 10 to 100 times higher at CAWS locations than at general use waters locations. Coliphage densities were higher downstream of the North Side and Calumet Water Reclamation Plants compared to upstream locations.

Protozoan Pathogens
Giardia was detected more frequently and in higher concentrations than *Cryptosporidium* at all locations. Within CAWS locations, both of the protozoan pathogens were present in higher concentrations and detected more frequently in the North system and South Branch compared to the Cal-Sag Channel. The average daily mean *Giardia* concentrations were higher downstream than upstream of both the North Side and Calumet Water Reclamation Plants. *Giardia* was frequently detected at recreation sites on general use rivers and inland lakes. This pattern of higher concentrations downstream of the Water Reclamation Plants seen with *Giardia* was not seen with *Cryptosporidium*.

Viral Pathogens
Adenovirus, norovirus, and enterovirus were measured in a subset of water samples in 2009. The concentrations of adenovirus and enterovirus viruses were similar in CAWS and inland lake locations, and were about 5-20 times higher than at Lake Michigan sampling locations. Norovirus was only detected in samples collected at, or just downstream, of a water reclamation plant.

The frequent detection of human viruses upstream of the water reclamation plants and in general use recreation waters (but not at the North Branch Dam) raises questions about virus sources. Bathers and other recreators may be sources of human viruses at inland lakes and Lake Michigan locations. At the North Branch Dam relatively high concentrations of the protozoan pathogens were detected but human enteric viruses were not. This suggests that the protozoan pathogens at this location may come from animals living in the forest preserve system.

General Observations
In general, the microbes measured were found more frequently and at higher concentrations at CAWS compared to general use waters. Among CAWS locations, microbe levels were higher on the North system (North Branch and lower North Shore Channel) compared to the Cal-Sag Channel. With the exception of *Cryptosporidium*, microbe concentrations were generally higher downstream of the water reclamation plants compared to upstream of the plants. Water that enters the CAWS at the Main Stem of the Chicago River was similar to Lake Michigan water, while water that enters the CAWS at the North Branch Dam had relatively high concentrations of protozoan pathogens.

Additional information about water quality at CAWS and other locations can be found in Chapter II of this report.

Executive Summary

Study participants

A total of 11,733 people completed the field interviews and 11,297 (96.4%) participated in a telephone follow-up. The distribution of the recreational activities of CAWS users who enrolled in CHEERS was similar to CAWS users in general (Table 1). Motor boaters accounted for a smaller proportion of CAWS study participants than they did of all observed CAWS users. Kayakers accounted for a higher proportion of CAWS study participants than they did of all observed CAWS users.

Water activity	CAWS users	CAWS study participants
Motor boating	35.8%	16.7%
Canoeing	17.2%	22.3%
Fishing	7.8%	10.7%
Kayaking	22.9%	34.2%
Rowing/other limited contact	15.4%	16.1%
Jet ski, wading, water skiing, diving/jumping, tubing	0.8%	0.0%
Total	**100.0%**	**100.0%**

Table 1: Distribution of recreational activities among all observed CAWS users and CAWS users who enrolled in CHEERS

Recreators were recruited into three study groups of comparable size. However, there were many differences in demographic, dietary, and other characteristics among the three groups. Among the two water-exposed groups (CAWS and general use waters), there were differences in the frequency of specific water recreation activities. Rowing and motor boating were more common among CAWS participants, while canoeing and fishing were more common among general use waters participants. Kayaking accounted for a similar proportion of recreational activities among study participants in the CAWS and general use waters groups. The CAWS and general use waters groups were different in terms of the amount of water exposure that was reported during recreation. For example, general use waters kayakers were more likely than CAWS kayakers to report that their face or head was drenched or submerged during recreation. The fact that the groups were not identical in important ways emphasized the need for data analysis methods that took group differences into account. These approaches are noted in the following section.

Additional information about study participants and differences among study groups can be found in Chapter III of this report.

Estimating the Number of Cases of Illness Attributable to CAWS Recreation

A multi-step process was utilized to evaluate the health risks of canoeing, fishing, kayaking, motor boating, and rowing. The steps, which were repeated for each health outcome, included:

- Develop a conceptual model that linked water recreation to illness
- Define time periods of interest for evaluating the occurrence of each type of illness
- Conduct statistical analyses to identify associations between study group and the risk of illness, after taking into account other differences between study groups (such as age composition or baseline health status)
- Estimate the frequency of illness attributable to CAWS recreation. This is different than simply calculating the frequency of illness among CAWS recreators, some of whom developed illness for reasons unrelated to their water activity.
- Check if the results of the analyses were simply a result of the specific statistical methods and definitions used

Additionally, the severity of illness was evaluated by asking study participants whether their symptoms resulted in the use of over-the-counter medication, evaluation by a healthcare provider (in person or via phone), interference with daily activities (such as work, school, or recreation), an emergency department visit, and/or hospitalization. Measures of illness severity were summarized for each type of illness, for all three study groups. Statistical testing evaluated whether differences in severity existed among the groups.

Additional information about data analysis methods can be found in Chapter IV of this report.

Gastrointestinal Illness in Relation to Study Group

A primary objective of this research was to determine the rate of illness attributable to CAWS recreation. This objective was met by analyzing the development of gastrointestinal and other types of illness in relation to study group. People in the CHEERS research study who developed diarrhea, vomiting, or disability from either nausea or stomach ache were considered to have acute gastrointestinal illness. From the time that recreation ended through the third day following recreation, 4.0% of study participants had developed acute gastrointestinal illness.

During the first three days following recreation, the odds of developing acute gastrointestinal illness were 26% higher in the CAWS group and 25% higher in the general use waters group, both compared to the unexposed group (the non-water recreators). These differences approached, but did not reach, statistical significance at the p=0.05 level. However, there were many differences between the groups, such as demographic characteristics and baseline health status, which could influence associations between study group and occurrence of acute gastrointestinal illness.

After taking into account differences among the groups, the odds of developing acute gastrointestinal illness were 41% higher in the CAWS group compared to the unexposed group. The odds of developing acute gastrointestinal illness were 44% higher in the general use waters group compared to the unexposed group. These associations were statistically significant.

The above findings were based on comparisons to the unexposed group. The odds of illness among CAWS and general use waters groups were also compared directly to one another. That comparison took into account two additional differences between groups that the comparisons to the unexposed group could not: the first was water exposure and the second was the participant's water recreation activity. After taking these differences into account, the odds of developing acute gastrointestinal illness were the same in the CAWS and general use waters group. However, water exposure did influence the occurrence of acute gastrointestinal illness in both study groups. Immediately following water recreation, study participants were asked to estimate how much water they swallowed. The response options were: none, a drop or two, a teaspoon, or at least a mouthful. The odds of developing acute gastrointestinal illness were five-fold higher among those who swallowed a mouthful or more of water compared to those who did not. Fishing and motor boating, compared to other limited contact recreation activities, are associated with a higher odds of developing acute gastrointestinal illness. This is surprising, as tables in Chapter III (Study Participants) demonstrate that only 1-2% of motor boaters and fishers reported swallowing water, while about 5% of rowers and paddlers did so. One possible explanation for the higher rate of gastrointestinal infection among fishers is that, in addition to contact with water, they also have contact with bait and with fish. We speculate that hand-to-mouth contact following bait or fish contact, rather than water exposure, has a stronger effect on the risk of illness among fishers.

Executive Summary

Factors linked with higher odds of developing acute gastrointestinal illness are listed in the table below.

Factors increasing the risk of AGI	Analysis of all participants	Analysis of water recreators
CAWS group (vs. unexposed)	√	No difference
General use waters group (vs. unexposed)	√	No difference
Female gender	√	√
Age 11-64 years (compared to <11 or >64 years)	√	√
African American race/ethnicity	√	√
Use of recruitment location 5-10 times (vs. less than 5)	√	No difference
Chronic GI condition	√	√
Higher perceived risk of CAWS use	√	√
More bowel movements per day at baseline	√	√
Water recreation activity	NA	Boating, fishing higher
Water ingestion	NA	√

The center column is for comparisons of all three groups. The right column is for comparisons of CAWS and general use waters users. √: Statistically significant association ($p<0.05$). NA: not applicable.

Results regarding the odds of illness describe how strongly study group was associated with the occurrence of acute gastrointestinal illness. The odds did not provide an estimate of how many cases of illness could be attributed to CAWS recreation. A different statistical approach, G-computation, was used to estimate this. After taking into account 20 potential differences between groups, for every 1,000 CAWS uses, about 12.5 recreators will develop acute gastrointestinal illness attributable to their limited contact water recreation activity. Although the number of 12.5 cases is an estimate, with 95% confidence that number is between 2.3 and 21.7 cases per 1,000 uses. As a comparison, for every 1,000 uses of the general use waters studied, about 13.4 recreators will develop acute gastrointestinal illness attributable to their limited contact water recreation activity. Although the number of 13.4 cases is an estimate, with 95% confidence that number is between 3.7 and 23.9 cases per 1,000 uses. The list below summarizes this information.

Risk of developing acute gastrointestinal illness

- CAWS vs. unexposed group:
  - Odds 41% higher
  - For every 1,000 uses, 12.5 cases attributable to water recreation
- General use waters group vs. unexposed group:
  - Odds 44% higher
  - For every 1,000 uses, 13.4 cases attributable to water recreation
- CAWS vs. general use waters group:
  - No statistically significant difference in odds
  - No statistically significant difference in the number of cases

Illness severity was evaluated by analyzing information collected during the telephone follow-up interviews from participants who developed symptoms of illness. Participants were asked whether their symptoms led them to use non-prescription and/or prescription medication; miss out on school, work, or other activities ("lost productivity"); seek medical care; and/or go to an emergency department or hospital. Illness severity was evaluated for participants who reported only acute gastrointestinal illness, and separately for all participants who developed acute gastrointestinal illness, including those who also had other symptoms (respiratory, skin, ear, or eye). Among study participants who developed acute gastrointestinal illness only, the majority reported no indicator of severity, and none reported an emergency department visit or hospital stay. There were no differences in severity among the three groups in terms of lost productivity. Among all study participants who developed acute gastrointestinal illness, about 30% reported no indicators of severity. About 50-60% used over-the-counter medication, and about 40-50% reported that their symptoms interfered with their usual activities. Few required prescription medication and less than 2% visited an emergency department or were hospitalized. Among those who had "any acute gastrointestinal illness" (including in combination with symptoms of other health endpoints), those in the two water recreation groups were significantly less likely to require prescription medication as those in the unexposed group. There were no differences in terms lost productivity.

Additional information about study group as a predictor of acute gastrointestinal illness can be found in Chapter V of this report.

Acute respiratory illness in relation to study group

Study participants who developed fever with nasal congestion, or fever with sore throat, or cough with phlegm were considered to have acute respiratory illness. During the first week of follow-up, 2.1% of study participants developed acute respiratory illness. Acute respiratory illness was no more common among those in the CAWS or general use waters groups, than in the unexposed group.

Direct comparisons of the CAWS and general use waters groups took into account two additional differences between groups. The first was water exposure and the second was each participant's specific water recreation activity. After taking into account these differences, the odds of developing acute respiratory illness remained the same in the CAWS and general use waters group. However, water exposure did influence the occurrence of acute respiratory illness. Immediately following water recreation, study participants were asked to estimate how much water they swallowed. The response options were: none, a drop or two, a teaspoon, or at least a mouthful. For each step up in the level of self-reported water ingestion the odds of developing acute respiratory illness doubled.

The factors related to developing acute respiratory illness are listed in the box below.

Factors increasing the risk of ARI	**Analysis of all participants**	**Analysis of water recreators**
Chronic Respiratory Condition	√	
Recent contact with someone with respiratory symptoms	√	√
Recent contact with cat or dog	√	√
Swallowing water	NA	√

The center column is for comparisons of all three groups. The right column is for comparisons of CAWS and general use waters users. √: Statistically significant association ($p<0.05$). NA: not applicable.

The estimated risks of acute respiratory illness are summarized below.

Risk of developing acute respiratory illness following limited contact recreation

- CAWS vs. unexposed group
  - No statistically significant difference in odds
  - No statistically significant difference in the number of cases
- General use water vs. unexposed group
  - No statistically significant difference in odds
  - No statistically significant difference in the number of cases
- CAWS vs. general use waters
  - No statistically significant difference in odds
  - No statistically significant differences in the number of cases

Differences in the severity of acute respiratory illness were not apparent among study groups.

Additional information about study group as a predictor of acute respiratory illness can be found in Chapter VI of this report.

Acute ear symptoms and study group

Study participants who developed ear pain or ear infection were considered to have acute ear symptoms. During the first week of follow-up, 1.2% of study participants developed acute ear symptoms. Compared to participants in the unexposed group, acute ear symptoms were no more likely to occur in the CAWS group or the general use waters group in the 7 days following recreation.

Factors increasing the risk of ear symptoms	**Analysis of all participants**	**Analysis of water recreators**
Female Gender	√	
Recent contact with someone with GI symptoms	√	√
Water exposure to head or face	NA	√

The center column is for comparisons of all three groups. The right column is for comparisons of CAWS and general use waters users. √: Statistically significant association ($p<0.05$). NA: not applicable.

Directly comparing the CAWS and general use waters groups took into account two additional differences between groups that the comparisons to the unexposed did not. The first was water exposure and the second was each participant's specific water recreation activity (motor boating, fishing, rowing, canoeing, or kayaking). After taking into account these differences, the odds of developing acute ear symptoms were the same in the CAWS and general use waters groups. However, water exposure did influence the occurrence of acute ear symptoms. Immediately following water recreation, study participants were asked to estimate much water exposure they had to their head or face. The response options were: none, sprinkled, splashed, drenched, or submerged. For each step up among the response options, the odds of developing acute ear symptoms increased by 48%.

After taking into account potential differences between groups, for every 1,000 limited contact uses there were essentially no excess acute ear symptom cases attributable to limited contact recreation on CAWS or general use waters.

Risk of developing acute ear symptoms following limited contact recreation

- CAWS vs. unexposed group
  - No statistically significant difference in odds
  - No statistically significant difference in the number of cases
- General use waters vs. unexposed group
  - No statistically significant difference in odds
  - No statistically significant difference in the number of cases
- CAWS vs. general use waters
  - No statistically significant difference in odds
  - No statistically significant differences in the number of cases

Additional details about study group as a predictor of acute ear symptoms can be found in Chapter VII of this report.

Skin rash and study group

New skin rash was reported by 4.0% of study participants. Skin rash was no more likely to occur in the CAWS group than in the unexposed group in the 3 days following recreation. The odds of developing a skin rash were 25% lower among those in the general use waters group than in the unexposed group. After taking into consideration demographic, medical, and exposure variables, the odds of developing skin rash were the same for the CAWS and unexposed groups. As summarized in the table below, people in the unexposed group had slightly higher odds of developing a rash than those in the general use waters group. In addition, several other factors were shown to increase the odds of skin rash: people who reported cuts, bug bites, or sunburn at baseline were more likely to report a skin rash during telephone follow-up. It was uncertain whether the reported rashes on follow-up were the same conditions (cuts, bug bites, or sunburn) that participants had at baseline, or new rashes.

Factors increasing the risk of skin rash	Analysis of all participants	Analysis of water recreators
CAWS group	Same as unexposed	
General use waters group	Lower than unexposed	
Skin cuts/wounds at baseline	√	√
Sunburn at baseline	√	√
Non-white race/ethnicity	√	
Bug bites at baseline	√	√
Being prone to infection	√	

Group and other factors associated with a higher risk of skin rash. The center column is for comparisons of all three groups. The right column is for comparisons of CAWS and general use waters users. √: Statistically significant association ($p<0.05$)

Directly comparing the CAWS and general use waters groups took into account two additional differences between groups that comparisons to the unexposed group did not. The first was water exposure and the second was each participant's specific water recreation activity (motor boating, fishing, rowing, canoeing, or kayaking). After taking these differences into account, the odds of developing skin rash were the same in the CAWS and general use waters groups. After taking potential differences between groups into account, for every 1,000 limited contact uses there were essentially no excess skin rash cases attributable to CAWS or general use waters recreation.

Risk of developing skin rash following limited contact recreation

- CAWS vs. unexposed group
  - No statistically significant difference in odds
  - No statistically significant difference in the number of cases
- General use water vs. unexposed group
  - 25% lower odds among the general use waters group
  - For every 1,000 uses, 11.1 fewer cases among general use waters group attributable to recreation
- CAWS vs. general use waters
  - No statistically significant difference in odds
  - No statistically significant differences in the number of cases

Additional information about skin rash and study group can be found in Chapter VIII of this report.

Eye symptoms and study group

Eye symptoms, which included eye redness, itching, discharge or crusting, were reported by 3.6% of participants within 3 days following recreation. If a participant considered their eye symptom to be related to usual allergies, the symptoms were not counted as a case of new eye symptoms. In the 3 days following recreation eye symptoms, the odds of developing new eye symptoms were 55% higher in the CAWS group compared to the unexposed group. Several other factors were shown to increase the odds of developing eye symptoms: people who perceived a higher risk of CAWS recreation were more likely, as were those who had recent contact with a person who had gastrointestinal symptoms. Children were less likely to report eye symptoms. The odds of reporting new eye symptoms were 37% higher in the CAWS group than in the general use waters group.

Executive Summary

Factors increasing the risk of eye symptoms	Analysis of all participants	Analysis of water recreators
CAWS Group	√	
Age 11-64 years (compared to 0-10 years)	√	√
Higher perceived risk of CAWS recreation	√	√
African American race/ethnicity	√	
Recent contact with someone with GI symptoms	√	
Motor boating (compared to canoeing, kayaking, and rowing)	NA	√
Getting hands wet		√
Uses water 5 days or less per year (compared to 11 days or more)	NA	√

The center column is for comparisons of all three groups. The right column is for comparisons of CAWS and general use waters users. √: Statistically significant association ($p<0.05$). NA: not applicable.

After taking into account potential differences between groups, for every 1,000 uses of the CAWS, about 15.5 developed acute eye symptoms attributable to their limited contact water recreation activity. Although the number of 15.5 cases is an estimate, with 95% confidence that number is between 6.3 and 24.2 cases per 1,000 uses. The above results involved comparisons of CAWS users to a group of non-water recreators. Compared to general use recreators, the odds of eye symptoms are 37% higher. If 1,000 people used the CAWS and 1,000 people used general use water for limited contact recreational activity, the CAWS group would be expected to have 11 additional cases of eye symptoms. This estimate takes into account water exposure, demographics, and other differences between the groups. Although the number of 11.1 cases is an estimate, with 95% confidence that number is between 1 and 21 cases per 1,000 uses.

Risk of developing eye symptoms following limited contact recreation

- CAWS vs. unexposed group
  - Odds 55% higher in the CAWS group
  - About 15-16 cases per 1,000 uses attributable to CAWS recreation
- General use waters vs. unexposed group
  - No statistically significant difference in odds
  - No statistically significant difference in the number of cases
- CAWS vs. general use waters
  - Odds 37% higher in the CAWS group
  - About 11 cases per 1,000 uses attributable to CAWS recreation

Eye symptoms were relatively low in severity. Among participants who only had eye symptoms, about 20% reported some indicator of severity. The most commonly reported indicator was the use of over-the-counter medication. Less than 3% visited an emergency department or hospital, and all of those were in the unexposed group.

Additional information about eye symptoms and study group can be found in Chapter IX of this report.

Pathogens responsible for gastrointestinal illness

A primary objective of this research was to characterize pathogens responsible for illness among CAWS recreators. This objective was met through an analysis of pathogens found in stool samples of participants with gastrointestinal symptoms. In the study, 10,998 participants (97.4%) had no gastrointestinal symptoms at baseline. A total of 2,467 (22.4%) developed new gastrointestinal symptoms (though not necessarily acute gastrointestinal illness, which has a more restrictive definition). Of those 2,467 symptomatic participants, a total of 745 (30.2%) provided a stool sample. A pathogen – a microbe that can cause disease - was identified in 79 samples from 76 participants (10.2% of those who provided samples). The most commonly identified pathogens were viruses, identified in stool samples from 70 of the 76 (92.1%) participants whose samples contained pathogens. Among the viral infections, 53 were due to rotavirus (76%), 14 were due to norovirus (20%), and three (4%) were due to other enteric viruses (echovirus and adenovirus). Protozoan and bacterial pathogens were identified in samples from 5 (7%) and 4 (5%) study participants, respectively. Pathogens that are often associated with severe disease, such as *Shigella, Salmonella*, or *E. coli* O157:H7, were not identified in any stool samples. The pathogen most frequently identified, rotavirus, usually causes infections among toddlers. In the CHEERS study, rotavirus was detected in stool samples from older children and adults. Non-water-related outbreaks of rotavirus among US adults have been described. Although rotavirus has previously been detected in stream water elsewhere in other settings, rotavirus infection has not been linked to outbreaks of recreational waterborne illness in the US.

The detection of pathogens in stool samples of participants with gastrointestinal symptoms was just as common for all three study groups. Pathogens presence was not associated with self-reported water ingestion. These two observations are not consistent with the assumption that CAWS use would be associated with the presence of waterborne pathogens in stool samples of study participants with gastrointestinal symptoms.

Additional details about pathogens isolated from clinical specimens can be found in Chapter X of this report.

Relationship between water quality and health risk

Six microbes (*E. coli*, enterococci, somatic coliphage, F+ coliphage, *Giardia, and Cryptosporidium)* were evaluated as predictors of each of five health outcomes (AGI, ARI, ear symptoms, eye symptoms, and skin rash). Concentrations of enterococci were predictors of AGI occurrence among recreators on general use waters; none of the microbes were predictors of AGI among CAWS recreators. Estimates of the risk of AGI for a given level of enterococci were dependent on the degree to which GUW participants were exposed to water. This is consistent with expectations, as those who have no exposure to water, regardless of microbe concentration, would be expected to remain free of illness attributable to water recreation. Conversely, those who have substantial water exposure would be expected to develop illness at lower microbe concentrations than those who have lesser degrees of exposure. For this reason, estimates of health risk as a function of water quality were generated for specific scenarios of population exposure, with exposure defined by the "wetness score," described in Chapters III and XI. Among recreators on general use waters, approximately 90% reported a wetness score of 10 or less. For those with a wetness score of 10, in other words, participants with a relatively high degree of exposure, a 10-fold increase in enterococci concentrations was associated with a 54% increase in the odds of developing AGI. The concentration of enterococci expected to result in specific numbers of excess cases of AGI attributable to limited contact recreation on general use waters for this scenario of heavy exposure (a wetness score of 10) are summarized in the table below.

Excess Cases per 1,000	**Enterococci concentration (CFU/100mL)**
5	1
10	2
15	7
20	19
25	46

Estimated cases of illness associated with enterococci concentrations on general use waters among recreators with a wetness score of 10

These estimates of cases of illness expected for a given concentration of microbes in general use waters is specific to those who had a particular degree of water exposure. In order to estimate overall cases of illness (including among those with greater and lesser degrees of water exposure) for a given concentration of enterococci, one must take into account 1) risk at each exposure level, and 2) the distribution of exposure levels among recreators. Using this integrated approach we estimate that rate of acute gastrointestinal illness attributable to general use water limited contact recreation would be about 11 cases per 1,000 when the enterococci concentration is 250 colony forming units per 100 mL. The rate is estimated to be about 13 cases per 1,000 when the concentration is 500 colony forming units per 100 mL.

In addition to microbe concentrations, two other potentially modifiable factors were associated with the development of acute gastrointestinal illness: exposure and, on the CAWS, recent combined sewer overflow events (CSO). In models of developing acute gastrointestinal illness with enterococci as a predictor, a CSO in the 24 hours prior to recreation was associated with a four-fold increase in the odds of illness among heavily-exposed recreators.

Additional information about the relationship between water quality and health outcomes can be found in Chapter XI of this report.

Conclusions

Study objective #1: Rates of illness attributable to CAWS recreation

- About 12-13 cases of gastrointestinal illness per 1,000 uses can be attributed to limited contact recreation on the CAWS. This rate is indistinguishable statistically from the rate of gastrointestinal illness attributable to limited contact recreation on general use waters.
- About 15-16 cases of eye symptoms per 1,000 uses can be attributed to limited contact recreation on the CAWS. This is higher than the rate of eye symptoms among limited contact users of general use waters.
- Respiratory, skin, and ear symptoms were not attributable to limited contact recreation at CAWS or general uses waters locations.

Study objective #2: Relationship between microbe concentration and health risk

- Of the six microbes studied, only enterococci was associated with the development of acute gastrointestinal illness, and only among recreators on general use waters. Microbial measures of water quality were not useful in predicting the development of acute gastrointestinal illness among CAWS recreators.
- The association between enterococci and acute gastrointestinal illness was only apparent among general use water recreators with above average degrees of water exposure.
- On the CAWS, recent combined sewer overflows were associated with a four-fold increase in the risk of developing illness among recreators with heavy water exposure.

Study objective #3: Pathogen responsible for illness

- The vast majority of pathogens identified in stool samples from study participants with gastrointestinal symptoms were viruses.
- Pathogens that often result in severe disease were not identified in stool samples.
- There was no suggestion that water recreation, CAWS use, or water ingestion were associated with gastrointestinal illness, though this possibility can not be ruled out.

Chapter XI. Water Quality and Health Outcomes

Section 11.01 Introduction

The second study objective of the CHEERS research study was to characterize the relationship between microbe concentrations in the CAWS and the rates of illness among recreators. This Supplement, which replaces Chapter XI of the August 31, 2010 report, addresses that study objective. Methods for measuring water quality and definitions of the five health outcomes of interest were described in Chapters II and V, respectively.

Section 11.02 Data analysis methods

(a) Linking water quality data to survey data

In order to analyze relationships between measures of water quality and the occurrence of illness, the water quality dataset (which included measures of indicators and pathogens) and the survey data (which included self-reported information about demographics, water exposure, and the health status of participants following water recreation) had to be linked to one another. A challenge in creating such a linkage was that study participants began and completed their water recreation throughout a recruiting day, while water quality was measured once per two hours for indicators and once per six hours for pathogens. Thus, water sampling did not coincide with the start/end time of recreation for each participant. Furthermore, water sampling and participant recruitment often took place at multiple locations per day. To create the linkage between the two datasets, all water quality and survey data were assigned a date-location-hour identifier. Each participant's survey data was then linked to the water quality data for the date-location-hour they started and finished their water recreation.

Often multiple water samples were collected on a given date, location, and hour for the same panel of microbial analyses. In such cases the replicate samples were averaged and the number of samples used in the calculation of each average was recorded. We assumed that if water quality data were not available at a location at a given hour, the best estimate of water quality would be the water quality data obtained at that location shortly before or after the hour of interest. An algorithm was developed using SAS software (SAS Institute, Cary, NC) that utilized the lag function (for water quality measures that took place in the hours following the start of recreation) and a lead function (for water quality measures that took place prior to the start of recreation) on a given location and date. For a given location and date, the algorithm selected water quality measured during the closest hour possible to the recreation starting or finishing time, choosing from water sampling time windows of plus or minus three, two, one hour from, and during the same hour of recreation. In the case where there was a match in both directions (before and after), the average was taken of the two. Once the closest match of water quality measurement for each recreation time was found, a new variable was created to describe what direction (lead or lag) and how many hours away (0-3) the water quality measure came from for each date-location-hour. As described in section 2.03 (b) of the August 31, 2010 CHEERS report, due to unacceptable variability of method performance, some *E. coli* and enterococci measures were unusable. Of the 1885 date-location-hours of water sampling, for *E. coli* (410) 21.7% did not have acceptable measures of *E. coli* concentration. Of the 1892 date-location-hours of enterococci sampling, 627 (33.1%) did not have acceptable measures of enterococci concentration.

Samples for which microbe densities were below the detection limit were assigned a value of 1/10 of the lowest detectable value for that microbe. The specific values assigned for below limit of detection F+ coliphage, somatic coliphage, *E. coli*, and enterococci were 0.1, 1.0, 0.1 and 0.1 per 100 mL, respectively. The value assigned for *Cryptosporidium* and *Giardia* measurements below the detection limit was 0.025 (oo)cysts/10L. The microbial measures of water quality were then $\log_{10}$ transformed to reduce distribution skewness.

(b) General approach for modeling health outcomes

Elements of the analysis of water quality as a predictor of health outcomes were:

- Develop a conceptual model linking waterborne microbes to health outcomes
- Define time windows of interest for defining the occurrence of each health outcome
- Develop multivariate logistic regression models of each health outcome using microbial measures of water quality as the main effects of interest
    - Evaluate potential effect modifiers
    - Evaluate potential confounders
    - Define a model selection procedure
- Based on the final models, generate figures and tables that relate water quality to health risk

This approach for analyzing health outcomes as a function of water quality shares many elements with the approach used to model health outcomes as a function of study group described in Chapter IV of the CHEERS Final Report. Specifically, conceptual models, potential confounders and effect modifiers, and time windows of interest have already been developed for the "group as predictor" analyses. Three important differences between conceptual models of illness that used study group as predictors (described in Chapters V-IX) and the analyses reported here are: 1) The analyses of associations between group and illness evaluated data from study participants in all three study groups (CAWS, GUW, UNX) while the analysis of water quality as a predictor of health outcomes utilizes data from the two groups of water recreators (CAWS, GUW). 2) The main effect of interest here is water quality (microbe concentration), rather than study group (CAWS or GUW), which was the case in the earlier analyses. 3) In the analyses of microbe concentration and health, the interest in evaluating "study group" is not to evaluate whether groups differences in risk exist. It is to determine whether illness as a function of microbe concentration should be analyzed separately for CAWS and GUW study participants.

Section 11.03 Development of multivariable logistic models

(a) Identify potential effect modifiers (interactions)

i. Study group

Flow from Chicago's combined (sanitary and storm) sewer system enters the CAWS during combined sewer overflow (CSO) events. Because CSOs may influence associations between microbe concentrations and health risks, it was necessary to first evaluate whether CSO events are associated with AGI, and if so, whether associations between microbes and illness among CAWS participants is modified by the occurrence of CSOs. If CSO occurrence independently predicts illness, or modifies associations between microbes and illness, illness risks of CAWS and GUW participants should be analyzed separately. If CSO events are not associated with illness and do not modify the microbe-illness association, the data from CAWS and GUW participants can be combined for analyses of microbe-illness associations.

ii. Water exposure

The acquisition of gastrointestinal infection is expected to occur after an infectious dose of one or more pathogens is ingested. The ingested dose is determined by two variables: the volume of water ingested and the concentration (density) of infectious microbe(s) of interest in the water. Thus, the relationship between water quality and health risk should depend on the volume of water ingested. Clearly, an individual who ingests no water would not acquire gastrointestinal infection no matter how high the pathogen concentration. Conversely, an individual who swallows a relatively large volume of water may acquire infection even if the pathogen concentration is relatively low. Because the degree of water ingestion influences the relationship between water quality and health risk, water exposure is by definition an effect modifier.

Two variables that characterize aspects of water exposure were evaluated as potential effect modifiers: a cumulative score of water exposure (the "wetness score") and self-reported water ingestion. Questions in the post-recreation survey ("Field Interview B") inquired about water contact to each of four body regions: head/face, upper extremities, torso, and lower extremities. For each of these body regions, participants estimated their degree of water exposure on an ordinal scale as "none" (scored as 0), sprinkled (1), splashed (2), drenched (3), or submerged (4). Scores (0-4 scale) for each of four body regions were summed to create a "wetness score," (0-16 scale). To put the wetness score in context, a person who swam and submerged his/her head would have a wetness score of 16. Distributions of wetness scores by study group are summarized in Table XI-1. Because there are more percentiles than there are levels of the wetness score, "ties" occurred. As was noted in Chapter III, Table XI-1 demonstrates that a larger proportion of GUW participants had high wetness scores.

Wetness score	CAWS Percentile of wetness score	CAWS Participants at/ below this percentile	GUW Percentile of wetness score	GUW Participants at/ below this percentile
0	0-17	610	0-15	577
1	18-21	773	16-20	731
2	22-29	1064	21-29	1007
3	30-38	1390	30-36	1316
4	39-51	1832	37-47	1734
5	52-61	2197	48-56	2079
6	62-74	2656	57-68	2513
7	75-83	3069	69-76	2904
8	84-91	3286	77-84	3109
9	92-95	3428	85-88	3243
10	96-97	3501	89-92	3313
11	98	3533	93-94	3343
12	99	3553	95-96	3362
13	99	3560	96	3368
14	99	3562	97	3371
15	99	3565	97	3373
16	100	3578	98-100	3385

Table XI-1: Percentiles of wetness scores, and cumulative frequency of wetness score, by study group.

Self-reported water ingestion, the second potential effect modifier related to water exposure, consisted of participant responses to questions about swallowing water. Responses were scored as none (0), a drop or two (1), a teaspoon (2), or a mouthful or more (3).

iii. Precipitation

Precipitation was considered to be a potential effect modifier because the relationship between indicator microbes and health risk may be different in dry weather, wet weather, and combined sewer overflow (CSO) conditions (Chicago has combined sanitary and storm sewers). Precipitation data from a grid of monitoring stations was obtained from the Illinois State Water Survey (http://www.isws.illinois.edu/data.asp) and was linked to locations of CHEERS water sampling. Data about CSOs were obtained from quarterly reports filed by the MWRDGC with the Illinois EPA. Time windows following precipitation events were defined (24, 48, 72, 96 hours) and characteristics of precipitation events (amount of rainfall, duration of rainfall) were summarized for each date-location-hour of CHEERS water sampling. The definitions of variables (in terms of time window width, amount, and duration of precipitation) that were most strongly associated with the outcome of interest in 30 models (five health outcomes, six microbes) with two-predictors (microbe and precipitation term) were selected for inclusion.

(b) Identify potential confounders of microbe-illness associations

Based on the conceptual models described in prior chapters (Chapter V for AGI), several potential confounders of associations between microbes and illness were identified. Association between the potential confounders and illness were evaluated in a series of single-predictor logistic models. For example, associations between AGI and age category, AGI and gender, AGI and dietary factors, etc, were defined. Variables associated with the outcome of interest were used as predictors in multivariate models of the occurrence of illness.

(c) Model selection

Two approaches to model selection were employed. The first was a backward selection process, which was conducted using the SAS logistic procedure's "Selection=backward" option. The second approach avoided model selection. As described in Chapter IV of the CHEERS report, the distribution of covariates in our study sample may influence our model selection process. To evaluate whether our findings may be generalizable to other settings, key analyses were repeated, avoiding model selection. In such models, multi-collinearity was evaluated by re-running the model using the SAS regression procedure using the option VIF (variance inflation factor).

General categories of covariates considered as possible confounders were: gender, race/ethnicity, medical variables (history of diabetes, being prone to infection, or a chronic GI condition), water recreation variables (recreational activity, perceived risk of CAWS recreation, frequent prior use of the same water recreation location, and subsequent water recreation during the follow-up period). In addition to the variables that were considered as potential confounders in models of all health outcomes, others were considered for specific outcomes. These covariates were identified in the conceptual models described in Chapter IV of the CHEERS report and are summarized in Table XI-2.

In addition to evaluating confounders, interaction effects between water quality predictors and potential effect modifiers as defined in the conceptual model were evaluated. For example, interactions between measures of water quality (microbe concentration or time since CSO) and water exposure (wetness score*microbe concentration) were evaluated to test whether water exposure modifies the water quality effect on health outcome. To determine whether microbes and exposures affect health differently in dry or wet weather, a three-way interaction term between weather, exposure, and water quality (recent rain*wetness score*microbe concentration) was tested.

	AGI	ARI	Eye	Ear	Skin
Recent dietary intake of:					
Fresh produce; hamburger, under-cooked meat, pre-packaged sandwich, runny/raw eggs	x				
Shellfish					x
Recent contacts					
Dog/cat	x	x			x
Animal other than dog or cat	x	x			
Person with GI symptoms	x	x	x	x	
Person with respiratory symptoms		x	x	x	
Person with eye symptoms			x		
Medical factors at baseline					
Antacid use	x	x			
Average number of daily bowel movements	x				
Chronic respiratory condition	x	x			
Recent antibiotic use	x	x			
Bug bites, sunburn, cut					x
Water exposure					
Swallow water score	x	x	x	x	
Subsequent water recreation during follow-up					x

Table XI-2: Variables considered in models of some, but not other health outcomes.

Odds ratios, adjusted for covariates, were reported for associations between microbes and the health outcome of interest. In an additive water quality effect model in which water quality does not interact with covariates, the odds ratio of water quality effect was based on the regression coefficient estimate. In a model with significant water quality and covariate interactions, odds ratios for associations between microbe concentration and health outcomes were estimated at different levels of the effect modifier using the contrast statement in logistic regression procedure in SAS PROC LOGISTIC.

(d) Methods of determining expected cases of illness based on microbe concentration

To determine the number of expected cases of illness for a given concentration of a microbe, we used a method similar to that which was utilized by NEEAR study researchers (Wade et al., 2006). We started with the logistic regression models described above which model the effect of microbe level on presence/absence of illness, adjusting for confounders. Then we obtained the predicted probability of illness at microbe concentrations of 1/10, 1, 10, 100, 1,000, and 10,000 per 100 mL. Predicted probability may be interpreted as cases of illness per a factor when multiplied by that factor. For example, a predicted probability of 0.01 translates to 10 cases per 1,000. Hence we used the predicted probability statistic from the logistic regression model to get to number of expected cases.

Every subject in the study had a potentially unique set of values for the other covariates in the model, hence every subject has a potentially unique predicted probability of illness. In order to estimate expected cases of illness, we obtained the predicted probability of illness for a hypothetical participant who had the average value of all covariates (other than microbe concentration). That is, we took the average values of each covariate adjusted for in the model, including categorical variables, such as age category, and continuous predictors, such as amount of precipitation, and estimated the predicted probability using those average values and the specified microbe level. If the model included a significant interaction term between microbe and water exposure, the fitted value of probability across the microbe concentrations was estimated at a range of values for water exposure, using the average value of all other covariates.

We calculated 95% confidence limits associated with the predicted probability of illness at each microbe level to use in plotting. We plotted the predicted probability points across the microbe values with the respective upper and lower confidence limit bands. We translated the axes of the plot for interpretability so that predicted probability of expected cases per 1,000 on the vertical axis was related to microbe concentration on a $\log_{10}$ scale on the horizontal axis. Interpreting these plots correctly is important. The most useful information comes from the slope. That is, for a 10-fold increase in microbe level (a unit change on a $\log_{10}$ scale), we estimated change in expected cases of illness per 1,000 uses. The significance of the slopes is determined by the significance of the coefficient of microbe in an additive (no interaction) model, or the significance of a contrast of microbe main effect, water exposure main effect, odds ratio of the association between microbe and illness, and the microbe by water exposure interaction, in a logistic model. We report odds ratios for associations between $\log_{10}$ microbe concentrations and illness, along with confidence interval, which are derived from main effect coefficients in an additive model, or contrast of parameters from an interaction model. Thus when the odds ratio for the association between $\log_{10}$ microbe and illness is not significantly different from one (i.e. the confidence interval around the odds ratio contains the value one), the plot for expected number of cases of illness for that microbe will have a slope that is nearly zero (i.e. the curve will be nearly flat). When the odds ratio for the association between $\log_{10}$ microbe and illness is significantly different from one, the curve in the plot will slope upward if the odds ratio is significantly greater than one (indicating a positive association between microbe exposure and illness), or the curve will slope downward if the odds ratio is significantly less than one (indicating a negative association between microbe exposure and illness.

For the microbes that were significantly associated with illness, we used the fitted regression model to solve for the level of microbe for which we expect to see an excess of 5, 10, 15, 20, and 25 cases of illness per 1,000 uses. This "excess" was determined from the "baseline" rate of illness, or the intercept of the model evaluated at the average value of each covariate. Again, the actual values of microbe associated with each level of excess cases should be interpreted with the understanding that it is determined by the intercept, rather than the slope, our primary interest in this analysis.

In order to correctly interpret the curves of expected number of cases of illness across microbe concentrations, recall that we computed expected number of cases as the predicted probability of illness using logistic regression models for each illness and microbe. Logistic regression models the log-odds of illness, or $\log\left(\frac{\Pr(illness)}{1-\Pr(illness)}\right) = \beta_0 + \boldsymbol{\beta X}$, where β_0 is the intercept and $\boldsymbol{\beta X}$ represents the matrix of covariates and their coefficients. If we solve for *Pr(illness)*, or predicted probability of illness, we get:

$$\log\left(\frac{\Pr(illness)}{1-\Pr(illness)}\right) = \beta_0 + \boldsymbol{\beta X}$$

$$\Leftrightarrow \frac{\Pr(illness)}{1-\Pr(illness)} = e^{\beta_0 + \boldsymbol{\beta X}}$$

$$\Leftrightarrow \Pr(illness) = \frac{e^{\beta_0 + \boldsymbol{\beta X}}}{1 + e^{\beta_0 + \boldsymbol{\beta X}}}$$

Hence our predicted probability is an exponential function, the graph of which curves upward as microbe concentration (our *x-values)* increases.

To understand the intercept and slope of the graph of predicted probability as a function of microbe concentrations, let's look at the log-odds equation. Consider a simplified model of AGI with covariates microbe and water exposure and the interaction between microbe and exposure:

$$\log\left(\frac{\Pr(illness)}{1-\Pr(illness)}\right) = \beta_0 + \beta_1 microbe + \beta_2 exposure + \beta_3 microbe * exposure\ .$$

When exposure is zero, for example, we have:

$$\log\left(\frac{\Pr(illness)}{1-\Pr(illness)}\right) = \beta_0 + \beta_1 microbe$$

Hence the log-odds of illness is a linear function of microbe concentration with intercept β_0 and slope β_1.

Now consider a different level of exposure, say, exposure is 10, we have:

$$\log\left(\frac{\Pr(illness)}{1-\Pr(illness)}\right) = \beta_0 + \beta_1 microbe + \beta_2(10) + \beta_3(microbe)(10)$$

$$= [\beta_0 + \beta_2(10)] + [\beta_1 + \beta_3(10)](microbe)$$

The intercept of the linear relationship is now $[\beta_0 + \beta_2(10)]$, an increase in intercept of $\beta_2(10)$, compared to the linear relationship between microbe and health when exposure is zero. The slope of the microbe effect is $[\beta_1 + \beta_3(10)]$, which is steeper, by a factor of $\beta_3(10)$, than the slope when exposure is zero.

(e) Calculating integrated rates of illness attributable to water quality

The fitted logistic model has the following functional form:

$$\log\left(\frac{P}{1-P}\right) = \beta_o + \beta_1 C + \beta_2 W + \beta_3 (C \times W) + \beta \mathbf{X},$$

where P is the probability of illness, C is the $\log_{10}$ microbe concentration, W is the wetness score which may take on values W ={0, 1, 2,… 16}, and **X** is a matrix demographic, medical, and exposure variables. The fitted coefficients are denoted β.

The logistic model can be rewritten to define the probability of illness as a function of exposure-related (e.g. C and W) and demographic variables (e.g. **X**)

$$P = \frac{1}{1 + \exp(-(\beta_o + \beta_1 C + \beta_2 W + \beta_3 (C \times W) + \beta \mathbf{X}))}.$$

The above expression implies that P is a function of C, W and **X**, and suggests that the number of illnesses expected at a given microbe concentration can be obtained by (1) summing the probability of illness summed across wetness scores using the average values of the demographic variables (e.g. **X**) or (2) by summing the probability of illness across all study participants.

The first approach is expressed as:

$$N_I = \sum_{i=0}^{12} P(C, \overline{\mathbf{X}} \mid W = i) \times n_i$$

where n_i is the number of participants to have wetness score W = *i*, and $\overline{\mathbf{X}}$ represents the values of the other logistic model variables averaged over the population.

The second approach is expressed as:

$$N_I = \sum_{i=i}^{n} P(C \mid \mathbf{X} = i, W = i)$$

which sums the probability of illness predicted for study participant *i* at microbe concentration C.

Using either approach yields an expected number of illnesses. The interest, however, is in the number of illnesses attributable to water recreation in water with a specified microbial concentration. If we define the expected risk to be:

$$R = \frac{N_I}{n}$$

and denote the background risk R_B, then the rate of illness attributable to water recreation can be computed as the difference between the observed and background rates of illness: $R_A = R - R_B$.

The background rate could be equated with the rate of illness expected in the study group given no water exposure – that is when the wetness score equals zero in the logistic model. However, since the logistic model includes a separate term for the microbe concentration, this approach will yield a background rate that varies with microbe concentration.

Section 11.04 Results: Microbes as predictors of acute gastrointestinal illness for CAWS participants

Of the five health outcomes studied, only the occurrence of AGI could be predicted using concentrations of indicator bacteria. For that reason, only the findings of the AGI analysis are presented in detail.

Step 1: Identify potential confounders based on bivariate association with AGI

A series of single-predictor models identified several variables that, in analyses of CAWS participants only, were associated with the occurrence of AGI in days 0-3. The variables, odds ratios of their association with AGI, and the confidence limits (CL) of those odds ratios, are summarized in Table XI-3.

Variable	Odds Ratio (95% CL)
Age 0-10	0.666 (0.291, 1.524)
Female gender	1.479 (1.076, 2.035)*
Race/ethnicity	
Hispanic (vs. all others)	0.841 (0.401, 1.763)
White (vs. all others)	0.513 (0.314, 0.840)*
Multiple (vs. all others)	0.599 (0.311, 1.155)
Pre-existing GI condition	2.192 (1.187, 4.050)*
Recent contact w/ person who has GI symptoms	0.895 (0.361, 2.219)
Activity (vs. fishing)	
Boat	0.805 (0.464, 1.398)
Canoe	0.690 (0.405, 1.176)
Kayak	0.721 (0.441, 1.178)
Row	0.508 (0.272, 0.949)*
Water sport concern	1.097 (1.032, 1.165)*
Use of same water 5-10 times in past year	1.349 (0.870, 2.090)
Water rec. during follow-up	1.074 (0.710, 1.625)
Avg. # daily bowel movements (baseline)	1.396 (1.111, 1.755)*
Antacid use	1.187 (0.664, 2.123)*
Recent antibiotic use	0.580 (0.212, 1.584)
Dietary exposures	
Fresh produce	1.404 (0.754, 2.615)
Hamburger	1.153 (0.815, 1.631)
Raw eggs	1.020 (0.470, 2.212)
Raw meat	1.149 (0.555, 2.382)
Shellfish	1.174 (0.669, 2.059)

Table XI-3: Bivariate associations between potential confounders and AGI, CAWS participants only. *p<0.05.

Step 2: Multivariate logistic model with model selection

All potential confounders identified in Table XI-3 were entered into a model of AGI that included enterococci. A backward model selection process was used and all predictors, including enterococci, were eliminated from the model other than gender, presence of a chronic GI condition, and average number of daily bowel movements. The inclusion of the wetness score and the interaction term of wetness score and enterococci had the same result. Forcing into the model terms for enterococci, wetness score, and the interaction of wetness score and enterococci found that even at the highest levels of exposure, enterococci was not a predictor of AGI (Table XI-4). The only predictors of AGI among CAWS participants that remained significant are summarized in Table XI-5.

Wetness score	Odds Ratio	95% CL	p-value
4	0.944	0.738, 1.206	0.642
5	0.963	0.742, 1.250	0.778
6	0.983	0.734, 1.318	0.911
7	1.004	0.716, 1.407	0.982
8	1.025	0.694, 1.513	0.902
9	1.046	0.669, 1.636	0.843
10	1.068	0.643, 1.774	0.799
11	1.091	0.617, 1.929	0.766
12	1.113	0.590, 2.100	0.740

Table XI-4: Adjusted associations between enterococci and AGI by strata of wetness score, CAWS participants.

The statistically significant predictors in this model were:

Effect	Odds Ratio	95% CL
Female gender (vs. male)	1.742	1.158, 2.620
Pre-existing GI condition (vs. none)	2.342	1.134, 4.839
Average number of daily bowel movements at baseline	1.482	1.115, 1.971

Table XI-5: Predictors of AGI among CAWS participants.

Step 3: Exploration of CSO rather than microbes as a predictor of AGI among CAWS recreators

Combined sewer overflow events were a priori thought to potentially impact the risk of AGI. To evaluate this possibility, a variable for the presence or absence of CSO in the prior 24 hours (interacting with the wetness score) was substituted for the enterococci term in the full model (which included all significant terms in Table XI-3). Such a model identified an interaction between CSO and wetness score on the occurrence of AGI. Table XI-6 demonstrates that for participants with a wetness score of 8 and higher, the odds of AGI following CAWS use are higher immediately following a CSO, compared to use of the CAWS in the absence of recent (24 hours) CSO activity. For example, for participants with a wetness score of 8 (which corresponds to approximately the 84-91st percentiles of wetness among CAWS participants), the odds of developing AGI are 1.91 times greater within 24 hours of CSO activity compared to other periods, a 91% increase. For those with higher exposure (wetness score=12), risk is increased by 400%. Covariates that were significant predictors of AGI in the model that included the CSO-wetness score interaction are listed, along with their odds ratios, in Table XI-7.

Wetness score	Odds Ratio	95% CL	Pr > ChiSq
4	0.912	0.459, 1.811	0.792
5	1.097	0.599, 2.008	0.764
6	1.320	0.750, 2.323	0.336
7	1.588	0.892, 2.827	0.116
8	1.911	1.011, 3.611	0.046
9	2.299	1.105, 4.783	0.026
10	2.767	1.179, 6.493	0.019
11	3.329	1.238, 8.950	0.017
12	4.005	1.287, 12.460	0.017

Table XI-6: Adjusted associations between CSO activity in the prior 24 hours and AGI, by strata of wetness score, CAWS participants.

Effect	Odds Ratio	95% CL
Female gender (vs. male)	1.604	1.157, 2.225
White race/ethnicity (vs. all others)	0.621	0.438, 0.882
Pre-existing chronic GI condition (vs. none)	2.149	1.147, 4.025
Rowing (vs. other activities)	0.593	0.358, 0.983
Perceived risk of CAWS recreation (ordinal)	1.094	1.029, 1.163
Avg. number of daily bowel movements at baseline	1.437	1.135, 1.819

Table XI-7: Adjusted associations between AGI and covariates, in the CSO-wetness score interaction model, CAWS participants.

The association between CSO and AGI observed among CAWS participants with relatively heavy water exposure was only apparent when the time window of interest was the 24 hours since CSO activity. With a definition of 48 hours, the associations were not statistically significant at the level of $p \leq 0.05$, though a trend towards higher odds of AGI with higher degrees of wetness was again apparent (Table XI-8).

Wetness score	Odds ratio	95% CL	Pr > ChiSq
4	0.623	0.350, 1.107	0.107
5	0.736	0.443, 1.224	0.238
6	0.870	0.539, 1.407	0.571
7	1.029	0.626, 1.693	0.910
8	1.217	0.697, 2.124	0.490
9	1.439	0.754, 2.746	0.270
10	1.701	0.799, 3.621	0.168
11	2.011	0.837, 4.833	0.118
12	2.378	0.870, 6.503	0.091

Table XI-8: Adjusted associations between AGI and the occurrence of CSO in the 48 hours prior to recreation, CAWS participants.

Step 4: Evaluate enterococci as a predictor of AGI for wet weather among CAWS participants

As demonstrated in Table XI-4, enterococci concentration was not a predictor of AGI among CAWS participants overall (wet and dry weather combined), taking into account the wetness score. To evaluate whether enterococci concentration may be a predictor of AGI in wet or dry weather only, subsets of the data were evaluated, based on whether CSO or precipitation had occurred during specified time intervals prior to recreation. Even at the highest levels of wetness score, associations between enterococci and AGI did not approach statistical significance (Table XI-9). Similar findings were obtained when wet weather was defined as precipitation or CSO within the prior 24, 48, or 72 hours. When wet weather was defined as precipitation within the past 96 hours, an association between enterococci and AGI was suggested only among recreators in the highest stratum of wetness score. This association did not reach statistical significance at the $\alpha = 0.05$ level (odds ratio 1.872 [0.935, 3.752], p=0.077).

Wetness score	Odds Ratio	95% CL	Pr > ChiSq
4	1.045	0.825, 1.3243	0.715
5	1.072	0.846, 1.357	0.567
6	1.099	0.855, 1.412	0.463
7	1.126	0.853, 1.487	0.402
8	1.155	0.843, 1.580	0.370
9	1.184	0.829, 1.691	0.354
10	1.213	0.810, 1.817	0.348
11	1.244	0.790, 1.960	0.346
12	1.275	0.769, 2.116	0.347

Table XI-9: Adjusted associations between AGI and $\log_{10}$ enterococci by strata of wetness score, participants who recreated on the CAWS within 48 hours of precipitation.

Step 5: Evaluate enterococci as a predictor of AGI for dry weather among CAWS participants

No association between enterococci and AGI was apparent under dry weather conditions, even for the strata of participants with the highest levels of exposure. This was true whether "dry weather" was defined as an absence of CSO in the past 24 hours (Table XI-10) or when it was defined as no precipitation in the prior 72 hours (Table XI-11).

Wetness score	Odds Ratio	95% CL	Pr > ChiSq
4	0.965	0.746, 1.246	0.782
5	1.000	0.758, 1.319	1.000
6	1.037	0.758, 1.419	0.821
7	1.075	0.748, 1.545	0.695
8	1.115	0.734, 1.695	0.611
9	1.156	0.716, 1.868	0.554
10	1.199	0.696, 2.066	0.514
11	1.243	0.675, 2.290	0.485
12	1.289	0.654, 2.542	0.464

Table XI-10: Adjusted associations between $\log_{10}$ enterococci and AGI among CAWS participants who recreated at least 24 hours after CSO activity.

Wetness score	Odds Ratio	95% CL	Pr > ChiSq
4	1.190	0.620, 2.287	0.601
5	1.140	0.622, 2.089	0.672
6	1.092	0.594 2.006	0.778
7	1.045	0.540, 2.023	0.896
8	1.001	0.472, 2.121	0.998
9	0.958	0.402, 2.284	0.924
10	0.918	0.337, 2.502	0.867
11	0.879	0.279, 2.773	0.826
12	0.842	0.229, 3.096	0.795

Table XI-11: Adjusted associations between AGI and $\log_{10}$ enterococci, by strata of wetness score, among participants who recreated on the CAWS at least 72 hours after precipitation.

Section 11.05 Results: Microbes as predictors of acute gastrointestinal illness for GUW participants

Step 1: Begin with potential confounders defined by bivariate association with AGI

A series of single-predictor models identified several variables that, in analyses of GUW participants only, were associated with the occurrence of AGI in days 0-3. The variables, and their association with AGI are summarized in Table XI-12.

Variable	**Odds Ratio (95% CL)**
Age 0-10	0.333 (0.122,0.906)*
Female gender	1.021 (0.734, 1.421)
Race/ethnicity	
Hispanic (vs. all others)	0.543 (0.232, 1.270)
White (vs. all others)	0.404 (0.211, 0.771)*
Multiple (vs. all others)	0.518 (0.228, 1.176)
Pre-existing GI condition	2.660 (1.544, 4.583)*
Recent contact w/ person who has GI symptoms	2.141 (1.097, 4.180)*
Activity (vs. fishing)	
Boat	1.301 (0.734, 2.307)
Canoe	0.583 (0.380, 0.893)*
Kayak	0.603 (0.396, 0.920)*
Row	0.272 (0.097, 0.762)*
Water sport concern	1.064 (0.999, 1.132)
Use of same water 5-10 times in past year	1.403 (0.845, 2.329)
Water rec. during follow-up	1.074 (0.710, 1.625)
Avg. # daily bowel movements (baseline)	1.124 (0.877,1.439)
Antacid use	1.709 (1.040, 2.809)*
Recent antibiotic use	1.642 (0.786, 3.430)
Dietary exposures	
Fresh produce	0.440 (0.292, 0.663)
Hamburger	1.216 (0.855, 1.729)
Raw eggs	1.093 (0.474, 2.522)
Raw meat	1.487 (0.742, 2.978)
Shellfish	0.713 (0.288, 1.763)

Table XI-12: Bivariate associations between potential confounders and AGI, GUW participants only.*p<0.05.

Step 2a: Multivariate logistic model with model selection

All potential confounders identified in Table XI-12 were entered into a model of AGI (among GUW participants) that included enterococci. A backward model selection process was used. Unlike the analysis of AGI of CAWS participants, enterococci concentrations did predict the occurrence of AGI among GUW participants with relatively high degrees of water exposure (Table XI-13). Without the wetness score and interaction term of AGI*wetness score, enterococci was not a predictor of AGI among GUW participants.

Step 2b: Multivariate logistic model without model selection

The results were robust to the inclusion or exclusion of numerous terms in the logistic model (Table XI-13). For the reduced model (following backward selection), the model predictors, in addition to $\log_{10}$ enterococci, wetness score, and the interaction term of $\log_{10}$ enterococci*wetness score were: pre-existing (chronic) GI condition, recent exposure to a person with GI symptoms, and recreational activity. In the full model, the terms were those included in the reduced model, along with age, race/ethnicity, baseline number of daily bowel movements, antacid use, and the presence of rain in the 24 hours prior to recreation. Covariates that were significant predictors of AGI among GUW recreators in the final are listed in Table XI-14.

	Reduced model			**Full model**		
Wetness score	**Odds Ratio**	**95% CL**	**p=**	**Odds Ratio**	**95% CL**	**p=**
4	1.090	0.880, 1.350	0.432	1.131	0.904, 1.415	0.282
5	1.155	0.937, 1.424	0.177	1.193	0.960, 1.484	0.112
6	1.225	0.987, 1.519	0.065	1.259	1.007, 1.572	0.043
7	1.298	1.029, 1.638	0.028	1.328	1.047, 1.684	0.020
8	1.376	1.064, 1.780	0.015	1.400	1.078, 1.818	0.012
9	1.459	1.093, 1.947	0.010	1.477	1.104, 1.976	0.009
10	1.547	1.119, 2.139	0.008	1.558	1.125, 2.158	0.008
11	1.640	1.141, 2.357	0.008	1.644	1.142, 2.365	0.008
12	1.738	1.161, 2.603	0.007	1.734	1.157, 2.598	0.008

Table XI-13: Adjusted associations between log10 enterococci and AGI, by strata of wetness score, GUW participants. See text for model details.

Variable	**Odds Ratio**	**95% CL**
Pre-existing chronic GI condition (vs. none)	2.975	1.550, 5.710
Recent contact w/ someone with GI symptoms	3.950	1.932, 8.076
Canoeing (vs. fishing, boating)	0.328	0.182, 0.591
Kayaking (vs. fishing, boating)	0.365	0.202, 0.658
Rowing (vs. fishing, boating)	0.202	0.060, 0.684

Table XI-14: Covariates with significant adjusted associations between AGI among GUW participants, in the enterococci*wetness score model.

Step 3: Evaluate an alternative characterization of water exposure

The analyses were repeated using the “swallowed water score” (a 4-level variable described in Section 11.04) instead of the wetness score as a means of stratifying participant exposure to water among GUW participants. As shown in Table XI-15 the trend is toward higher odds ratios at higher levels of self-reported water ingestion. However, only 4% of study participants reported swallowing any water, and less than 0.5% reported swallowing a mouthful of water. For this reason the wetness score, for which considerable variability across individuals was present, was a better term for characterizing exposure than was the degree of self-reported ingestion.

Swallowed water	Odds Ratio	95% CL	Pr > ChiSq
None	1.251	0.786, 1.992	0.345
Drop	1.326	0.536, 3.278	0.542
Teaspoon	1.404	0.360, 5.483	0.625
Mouthful	1.487	0.240, 9.208	0.670

Table XI-15: Adjusted associations between log10 enterococci and AGI, by strata of self-reported water ingestion, GUW participants.

Section 11.06 Results: Concentration-risk relationships

(a) Graphical summaries

The relationships between the risk of AGI and microbe concentrations are presented in the three figures below. These results are limited to analyses of GUW recreators, as microbe concentrations were not found to predict AGI among CAWS recreators. The three figures are meant to depict the enterococci-AGI association at different levels of water exposure. If all GUW recreators had a wetness score of 5 (approximately the median value), no association between enterococci concentration and AGI would be expected, as Figure XI-1 shows a relatively flat line, consistent with the idea that no association between enterococci concentration and AGI is apparent for the typical GUW recreator. Figure XI-2 shows a steeper increase in risk with increasing log10 enterococci concentration for those with a wetness score of 7, which corresponds to approximately the upper 25% of GUW recreators. Figure XI-3 shows a steeper increase still for those with a wetness score of 10, approximately the top 10% of GUW recreators. This indicates that with increasing microbe concentrations in GUW waters, additional cases of AGI are expected.

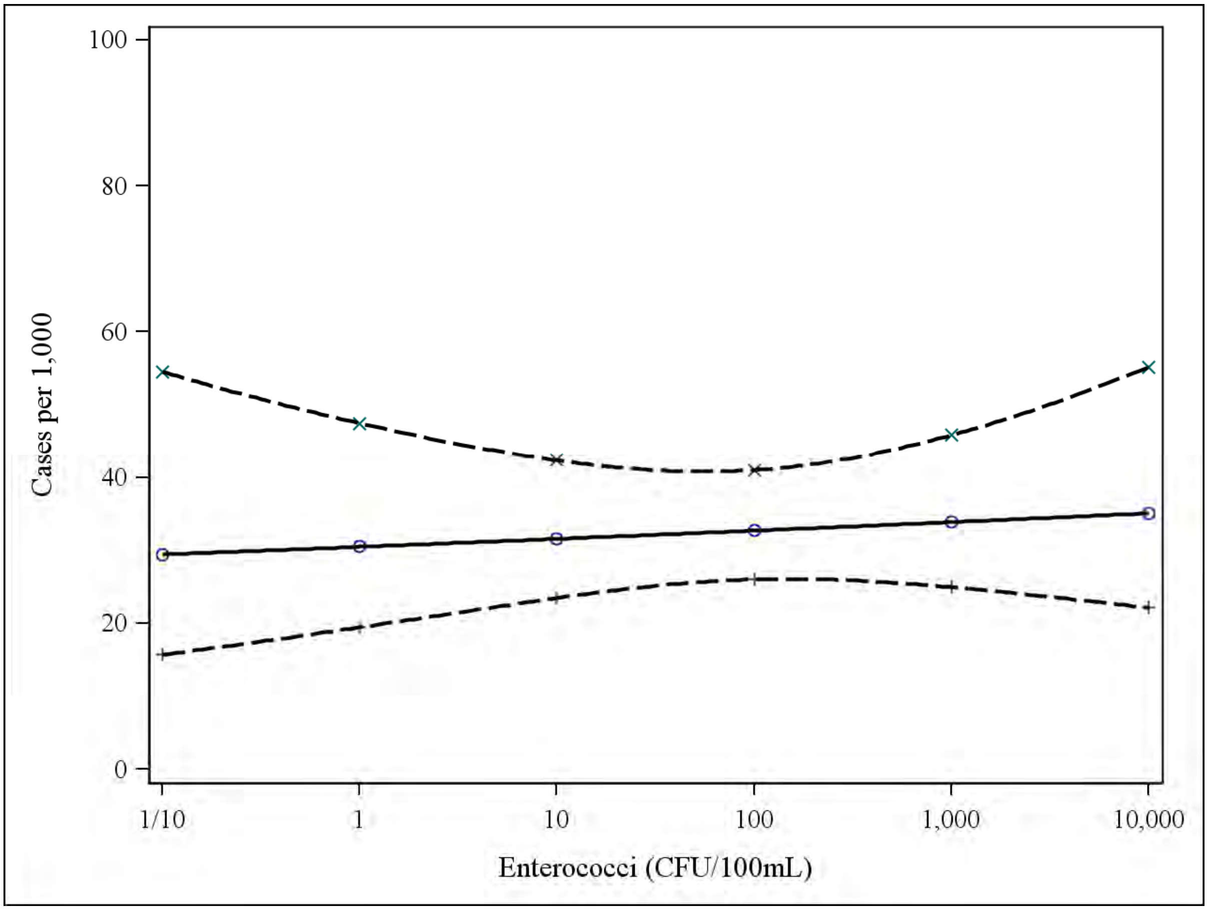

Figure XI-1: Relationship between enterococci concentration in GUW waters and AGI risk for participants with a wetness score of 5.

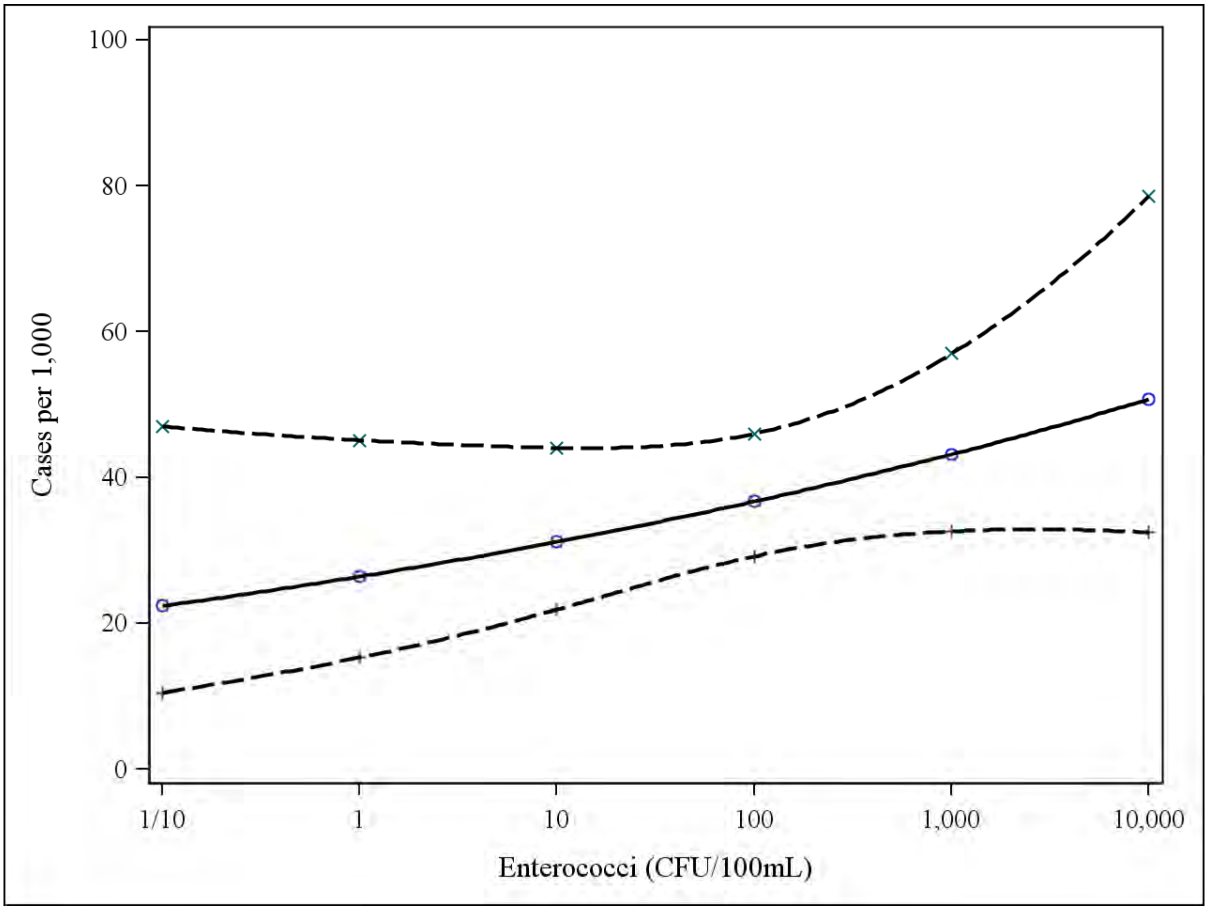

Figure XI-2: Relationship between enterococci concentration in GUW waters and AGI risk for participants with a wetness score of 7.

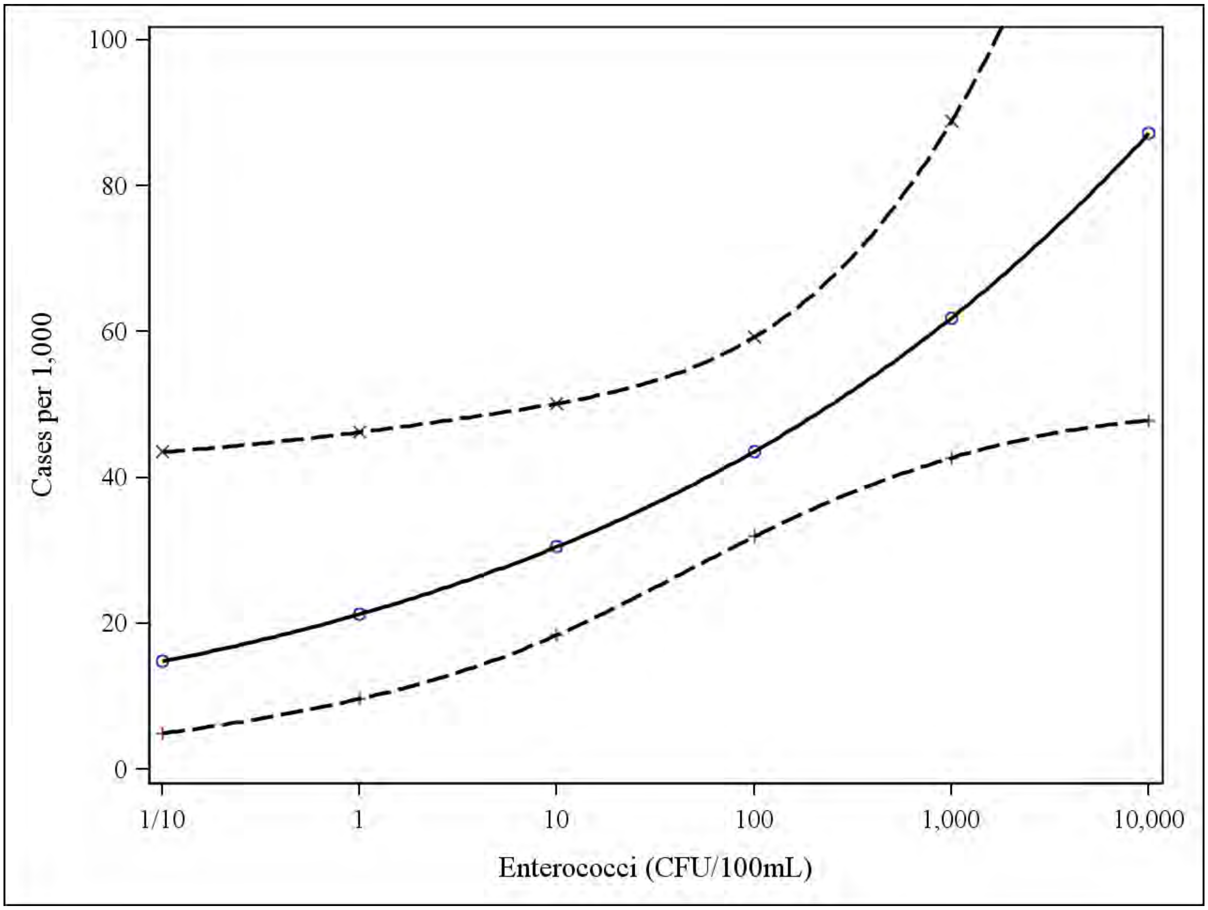

Figure XI-3: Relationship between enterococci concentration in GUW waters and AGI risk for participants with a wetness score of 10.

(b) Expected cases of AGI attributable to microbe concentration, by level of exposure

Using the method described in section 11.03 (d), "Methods of determining expected cases of illness based on microbe concentration," enterococci-AGI models specific to strata of the wetness score were used. The information presented in Table XI-16 summarizes results of these analysis. For example, for 1,000 GUW recreators all of whom had a wetness score of 8, five would be expected to develop AGI attributable to water recreation if the enterococci concentration was 1 CFU/100mL. If the enterococci concentration was 5 CFU/100mL, 10 cases of AGI attributable to water recreation would be expected. If the enterococci concentration was 22 CFU/100mL, 15 cases of AGI attributable to water recreation would be expected. However, an expected 15 cases of AGI attributable to water recreation would require a lower enterococci concentration – 11 CFU/100mL – among recreators with a wetness score of 9.

	Cases of AGI per 1,000 uses				
Wetness score	**5**	**10**	**15**	**20**	**25**
6	3	96	2,044	30,833	355,282
7	1	11	84	497	2429
8	1	5	22	87	291
9	1	3	11	34	92
10	1	2	7	19	46
11	0.5	2	5	13	29
12	0.5	2	5	10	21
13	0.5	2	4	9	16

Table XI-16: Concentrations of enterococci (CFU/100 mL) expected to result in given numbers of cases of AGI per 1,000 general use water recreators, by wetness score.

(c) Expected number of cases of AGI attributable to microbe concentration across all levels of "wetness score" among GUW recreators

Using the method described in section 11.04 (e), expected cases of AGI for each stratum of wetness score were calculated and weighted by the distribution of GUW recreators across strata. Total and attributable cases (total-background) were calculated and summarized in Table XI-17. This demonstrates that an estimated 10.7 cases per 1,000 limited contact recreators would develop AGI on GUW waters if the enterococci concentration were 250 CFU/100mL. If the concentration were 500CFU/100mL, 13.1 cases/1,000 would be expected. Background rates of AGI are different in the enterococci=250 CFU/100mL and the enterococci=500 CFU/100mL scenarios. This difference results from the inclusion in the model of a term for enterococci (which is 0 in neither model) as well as the interaction of enterococci*wetness score (which is 0 at baseline).

		Enterococci=250 CFU/100mL				Enterococci=500 CFU/100mL			
Wetness score	GUW recreators (per 1,000)	Probability	Expected cases per 1,000	(Expected-background)	Attributable cases/1,000	Probability	Expected cases per 1,000	(Expected-background)	Attributable Cases/1,000
0	170.4	0.022	3.715	0	0.000	0.020	3.404	0	0
1	45.5	0.024	1.080	0.002	0.087	0.022	1.010	0.002	0.1
2	81.4	0.026	2.099	0.004	0.325	0.025	2.000	0.005	0.375
3	91.3	0.028	2.563	0.006	0.572	0.027	2.491	0.007	0.667
4	123.6	0.031	3.770	0.009	1.076	0.030	3.737	0.01	1.268
5	101.8	0.033	3.377	0.011	1.157	0.034	3.413	0.014	1.379
6	128.4	0.036	4.630	0.014	1.829	0.037	4.770	0.017	2.204
7	115.4	0.039	4.519	0.017	2.003	0.041	4.747	0.021	2.441
8	60.6	0.043	2.580	0.021	1.258	0.046	2.761	0.026	1.55
9	39.7	0.046	1.832	0.024	0.967	0.050	1.999	0.03	1.206
10	20.5	0.050	1.027	0.028	0.580	0.056	1.141	0.036	0.732
11	9	0.054	0.487	0.033	0.292	0.062	0.552	0.042	0.373
12	5.6	0.059	0.332	0.037	0.210	0.068	0.383	0.048	0.27
13	1.8	0.064	0.115	0.042	0.076	0.075	0.135	0.055	0.099
14	0.8	0.069	0.053	0.048	0.037	0.083	0.064	0.063	0.048
15	0.8	0.075	0.058	0.053	0.041	0.091	0.070	0.071	0.055
16	3.6	0.081	0.292	0.06	0.213	0.100	0.360	0.081	0.288
	1,000	**Total**	**32.529**		**10.723**		**33.037**		**13.1**

Table XI-17: Predicted cases of AGI attributable to water recreation on general use waters for two values of water quality.

Section 11.07 Microbes as predictors of other health endpoints

The above analyses addressed associations between limited contact recreation and the development of acute gastrointestinal illness. Four other health outcomes were evaluated: acute respiratory illness (ARI), acute ear symptoms, eye symptoms, and skin rash. The occurrence of these other health outcomes, as well as AGI, were modeled as functions (in separate models) of *E. coli*, enterococci, somatic coliphage, F+ coliphage, *Cryptosporidium*, and *Giardia* concentrations. Models included interaction terms of microbe, exposure, and microbe*exposure. If an interaction was present, the p-values for associations between microbe and outcome were evaluated for wetness score=10. If no interaction was present, only the microbe term, along with demographic, recreational activity, perceived risk, and the covariates listed in Table XI-1 were included. As demonstrated in Table XI-18, health risks were not related to microbe concentration for CAWS recreators in dry conditions. Under wet conditions, coliphage concentrations were associated with the occurrence of respiratory and ear symptom (Table XI-19). The development of AGI was associated with concentrations of enterococci among GUW recreators as described above. An association between enterococci and eye symptoms was suggested, though the p-value did not reach statistical significance (Table XI-20). An association between skin rash and Cryptosporidium was also present.

	AGI	ARI	Ear	Eye	Skin
E. coli	0.549	u	0.934	0.153	0.773
Enterococci	0.797	u	0.933	0.421	0.930
Somatic coliphage	0.338	u	0.297	0.337	0.872
F+ coliphage	0.882	0.916	0.699	0.217	0.457
Giardia	0.722	u	0.671	0.739	0.681
Cryptosporidium	0.360	u	0.676	0.878	0.313

Table XI-18: p-values of association with health outcomes, CAWS recreators, dry conditions (no precipitation in the prior 72 hours).
u=unstable model with few observations per cell.

	AGI	ARI	Ear	Eye	Skin
E. coli	0.176	0.202	0.741	0.659	0.981
Enterococci	0.783	0.121	0.465	0.147	0.368
Somatic coliphage	0.101	0.222	**0.047**	0.666	0.808
F+ coliphage	0.154	**0.058**	0.222	0.138	0.436
Giardia	0.111	u	0.200	0.935	0.557
Cryptosporidium	0.253	u	0.606	0.984	0.577

Table XI-19: p-values of association for health outcomes, CAWS recreators, wet conditions (precipitation in the prior 72 hours).
u=unstable model with few observations per cell.

	AGI	ARI	Ear	Eye	Skin
E. coli	0.448	0.569	0.653	0.963	0.725
Enterococci	**0.007**	u	0.610	0.070	0.599
Somatic coliphage	0.522	0.887	0.740	0.289	0.830
F+ coliphage	0.886	0.882	0.904	0.789	0.851
Giardia	0.279	u	0.371	0.606	0.220
Cryptosporidium	0.717	u	0.885	0.766	**0.050**

Table XI-20: p-values of microbe or microbe x wetness association for health outcomes, GUW recreators.
u=unstable model with few observations per cell.

Section 11.08 Summary and Discussion

Relationships between microbial measures of water quality and health outcomes among limited contact water recreators were described. Of the six microbes evaluated, only concentrations of enterococci were consistently predictive of AGI occurrence. This association was limited to GUW recreators. Estimates of the risk of AGI for a given level of enterococci were dependent on the degree to which participants were exposed to water. This is consistent with expectations, as those who have no exposure to water, regardless of microbe concentration, would be expected to remain free of illness attributable to water recreation. Conversely, those who have substantial water exposure would be expected to develop illness at lower microbe concentrations than those who have lesser degrees of exposure.

Associations between enterococci and AGI were apparent for GUW recreation but not for CAWS recreation. Stratifying the analysis by degrees of the "wetness score" and adjusting for the presence of pre-existing (chronic) GI conditions, which was strongly associated with the development of AGI, should have reduced confounding due to those variables. The basis for this difference between the predictive value of enterococci for CAWS vs. GUW recreation is not known.

A method for describing risk integrated over a range of exposure values was applied to GUW locations as an example. Future analyses could compare this approach to averaging probabilities across participants, rather than calculating the probability for an "average" participant, though substantial differences in approaches are not anticipated. The analysis suggest that the rates of AGI attributable to water recreation would be about 11/1,000 on GUW waters if the enterococci concentration was 250 CFU/100mL and about 13/1,000 on GUW waters if the enterococci concentration was about 500 CFU/100mL. These estimates of cases per thousand are applicable to GUW recreation but not to CAWS recreation, as associations between enterococci and AGI were not identified among CAWS recreators.

Studies of the health risk of swimming at beaches USEPA (1984) identified both enterococci and *E. coli* as predictors of AGI, while in our setting only enterococci predicted AGI. Associations between F+ coliphages and AGI have been identified in a study of swimmers at beaches not heavily impacted by point sources of human fecal pollution (Colford et al., 2007) and in a study of whitewater canoeing on a slalom course heavily impacted by wastewater (Lee et al., 1997). We did not observe associations between F+ coliphages and AGI.

In addition to microbe concentrations, two other potentially modifiable factors were associated with the development of AGI: exposure and CSO events. Exposure could potentially be reduced through educational efforts directed toward discouraging capsizing. Improvements in storm water management should reduce the impacts of storm water on recreator risk. Avoidance of limited contact recreation on the CAWS would be prudent following CSO events.

Limitations of this study include the fact that in limited contact recreational activities, water exposure in general, and water ingestion in particular, occurs sporadically, and at different locations throughout an individual's recreation on the water. In this study water was sampled every two hours for indicators and every 6 hours for pathogens, and at points where recreation began and ended. Thus, it is likely that our estimates of microbe concentration do not perfectly reflect the exposure of individuals. There is no reason that the estimates of water quality we utilized as surrogates for individual exposure systematically over- or under-estimated microbe concentrations at the time and place of exposure. In general, such imperfect estimation of exposure would bias epidemiologic results towards the null. In other words, hypothetical measurements of microbe concentrations to which individuals were actually exposed (or ingested) may have been more strongly associated with the health outcomes we described. Nevertheless, like prior epidemiologic studies of water recreation and health, we utilized the best available data as a surrogate for personal exposure.

Another limitation is that *E. coli* data was only available for 5,371 of the 7,710 water recreators (69.7%) and enterococci data for 5,040 (65.4%). As described in Chapter II of the CHEERS Final Report, this was due to periods of unacceptable variability in microbe recovery in the laboratory that analyzed the water samples.

We have not compared the relationship between water quality and AGI observed in this study to those estimated for the NEEAR or other studies. This should be done with caution, recognizing that in CHEERS AGI was defined by the occurrence of symptoms on days 0-3 following water recreation, as opposed to 10-12 days after recreation in the NEEAR study. Days 0-3 were selected in CHEERS because illness attributable to water recreation was most apparent during this time period, as described in Chapter V of the CHEERS final report.

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