

Microbial risk assessment for recreational use of the Chicago Area Waterway System

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ABSTRACT

A microbial risk assessment was conducted to estimate the human health risks from incidental contact recreational activities such as canoeing, boating and fishing in the Chicago Area Waterway System (CAWS) receiving secondary treated, but non-disinfected, effluent from three municipal water reclamation plants. Actual concentrations of the pathogens (pathogenic *E. coli* [estimated], *Giardia*, *Cryptosporidium*, adenovirus, norovirus, enteric virus) detected from the waterway field data collection at locations upstream and downstream of the effluent outfall during dry and wet weather conditions within the recreation season were included in the risk assessment. The results under the current treatment scheme with no disinfection indicated that the total expected gastrointestinal illness (GI) rate per 1000 incidental contact recreational exposure events during combined weather (dry and wet) conditions ranged from 0.10 to 2.78 in the CAWS, which is below the eight illnesses per 1000 swimmers considered tolerable by the United States Environmental Protection Agency. Wet weather conditions contribute to elevated pathogen load to the CAWS; therefore this study determined that disinfecting the effluents of three major WRPs that discharge to the CAWS would result in an extremely small reduction in the aggregate recreation season risk to incidental contact recreators.

Key words | disinfection, microbial risk assessment, Monte Carlo simulations, pathogens, probabilistic, recreational exposure

INTRODUCTION

The Metropolitan Water Reclamation District (District) owns and operates three of the world's largest water reclamation plants (WRPs), in addition to four other plants and 23 pumping stations. The District's seven modern WRPs serve a population equivalent of 10.35 million people and can treat an average of 1.6 billion gallons of wastewater each day. These WRPs provide excellent treatment for residential and industrial wastewater, meeting permitted discharge limits at virtually all times. Stormwater in the separate sewered area is controlled to reduce flood damage by a number of stormwater

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detention reservoirs. In the combined sewer area, the District's tunnel and reservoir plan (TARP) has significantly reduced overflows to local waterways.

The secondary treated wastewater effluent from three major WRPs (North Side, Stickney and Calumet) is discharged into man-made canals called the Chicago Area Waterway System (CAWS). The CAWS consists largely of man-made channels which have steep embankments, lack shade and have a controlled flow manipulated by locks and dams to adjust the water levels based on anticipated rain events. The components of the CAWS that were once naturally occurring rivers have been significantly and irreparably altered for the purpose of draining stormwater and treated

wastewater away from Lake Michigan and for supporting commercial navigation. Commercial barge traffic is prevalent in the CAWS. These characteristics do not provide suitable habitats for aquatic life or primary recreational activities. Other than to contain and convey urban flowing water, the system bears little similarity in form or function to natural river systems (District 2008). The Chicago metropolitan area has grown and thrived as a result of the CAWS and its primary purposes are to protect the Lake Michigan drinking water supply, sustain this metropolis and protect it from flooding.

Primary contact recreation activities on the CAWS are prohibited because of unsafe conditions caused by other simultaneous uses such as commercial and recreational navigation, and the unique physical features of the CAWS. A recent Use Attainability Analysis (UAA) conducted by the Illinois Environmental Protection Agency (IEPA) determined that swimming should not be a designated use. Incidental contact uses such as fishing, boating, canoeing and streamside recreational activities were identified as designated uses for most portions of the CAWS (IEPA 2007). The IEPA did not develop water quality standards, but rather proposed an effluent limitation of 400 faecal coliform (FC) bacteria colony forming unit per 100 mL (cfu/100 mL) to be protective for fishing and boating, also known as secondary contact or incidental immersion with little or no ingestion of water.

Even though disinfection is a widely practised technology, there have been no studies performed to assess health risks for people exposed to water in the CAWS during incidental contact recreation. An item of concern regarding protecting the proposed CAWS recreational uses is the so-called 'waterborne disease potential' by microbial pathogens of human faecal origin. Based on the national surveillance of waterborne disease outbreaks reported by Centers for Disease Control and Prevention (CDC), outbreaks, especially the largest ones, have occurred during summer months and in recreational facilities such as spas, whirlpools and hot tubs (Yoder et al. 2008). The majority of the reported recreational water-associated outbreaks occurred at disinfected recreational water facilities. Since there are no scientific studies in the United States that characterize the health risks of incidental contact recreational activities, it is difficult to effectively evaluate the health impacts from recreating in the CAWS. An American Academy of Microbiology report

favours strong, environmental, science-based water regulation as a means of protecting public health (American Academy of Microbiology 2007). Therefore, it has been correctly concluded that it is unknown whether the United States Environmental Protection Agency's (US EPA) current primary contact criteria for bacteria are suitable or applicable for the protection of human health relative to the proposed designated recreational uses for the CAWS (District 2006; IEPA 2007).

This microbial risk assessment (MRA) study was initiated to generate the scientific information necessary to understand the public health uncertainties and to ascertain health risk from incidental contact recreation in the CAWS. The key focus in this investigation was to quantify the health risks to recreational users of the CAWS due to incidental contact pathogen exposure under dry and wet weather conditions. The study also quantified any reduction of health risks that would result from disinfection of WRP effluents discharged to the CAWS. One of the objectives of the MRA was to evaluate the health risk resulting from incidental contact recreation during wet weather periods when combined sewer overflows (CSOs) impact the CAWS. MRA probabilistic techniques were used to quantitatively assess health risks. The risks were estimated from recreational users participating in activities involving different levels of exposure in dry, wet or a combination of weather events over the course of the recreational season in 2005 and 2006. Probabilities of primary gastrointestinal (GI) illness were estimated based on established dose-response relationships for the microbial pathogens (pathogenic *E. coli* (estimated), enteric viruses, adenoviruses, noroviruses, *Giardia* spp. and *Cryptosporidium* spp.) measured in the CAWS.

METHODOLOGY

Description of the Chicago Area Waterway System

The 78-mile-long navigable CAWS, as shown in Figure 1, includes the North Shore Channel (NSC), North Branch Chicago River (NBCR), Chicago River Main Stem (CR), South Branch Chicago River (SBCR), South Fork South Branch Chicago River (SFSFCR), Chicago Sanitary and Ship Canal (CSSC), Calumet River, Little Calumet River

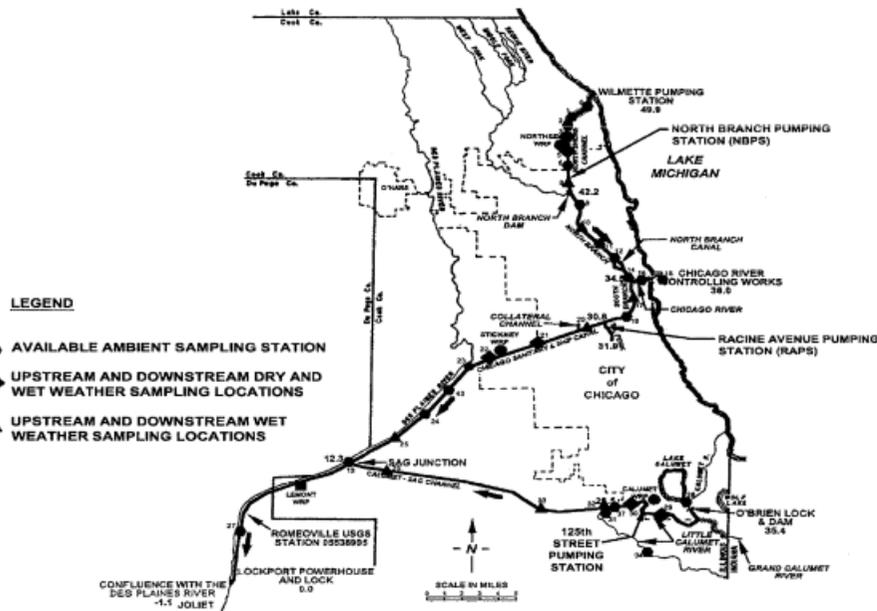


Figure 1 | Map of the Chicago Area Waterway System (CAWS).

(LCR), Calumet-Sag Channel (CSC), Grand Calumet River and Lake Calumet. The CAWS receives flow from the District's WRPs, from stormwater run-off, CSOs and diversion water from Lake Michigan. The system was engineered to convey urban drainage away from Lake Michigan. Flow is controlled by a series of locks and dams and the CAWS is tributary to the Des Plaines Rivers and ultimately the Mississippi River.

The CAWS is divided into three sections, North Side, Stickney and Calumet, corresponding to the three major WRPs (North Side, Stickney and Calumet) along the waterway. The North Side WRP discharges to the NSC, which flows into the NBCR; the Stickney WRP discharges to the CSSC; and the Calumet WRP discharges to the LCR that in turn discharges into the CSC. These WRPs are conventional activated sludge secondary treatment plants with extended aeration to produce nitrified effluents with ammonia, five-day biochemical oxygen demand (BOD_5) and suspended solids concentrations that are nearly an order of magnitude below their National Pollutant Discharge Elimination System (NPDES) permit limits. Currently, most of the CAWS regions have no water quality standards for bacteria. Due to water quality improvements over the years resulting from WRP upgrades and long-term control plan implementation for CSO reduction, there has been an increase in incidental contact recreational use. The Chicago River and its associated

waterways are part of a system that is secondary treated effluent dominated. Overall, approximately 75% of the flow in the CAWS originates from District WRPs. During rain events, in addition to the WRP effluents, several sources contribute to the microbial load in the CAWS: CSOs, discharges from storm drains and over-land run-off (District 2008).

Study approach

In the past, MRA has been used to assess the risks from microorganisms in drinking water (Haas 1983; Regli et al. 1991; Jaidi et al. 2009). In addition, MRA methodology to assess microbial risks for a variety of activities and microorganisms has been studied (Gerba et al. 1996; Haas et al. 1996; Crabtree et al. 1997; Haas et al. 1999; Pouillot et al. 2004) and used by the US EPA and international agencies such as World Health Organization (Parkin 2008) to quantitatively assess the health risks during use of recreational waters that receive effluent discharges (Soller et al. 2003).

The CAWS MRA was conducted in alignment with International Life Sciences Institute's (ILSI) risk assessment principles and methods (ILSI 2000). The MRA process in this study involved four steps as described in the literature (US EPA 1989; NRC 1994; ILSI 2000). The first step identified the recreational hazards of the CAWS that may expose individuals through incidental ingestion, inhalation of and

dermal contact to pathogenic bacteria, viruses and protozoa in the waters. Exposure to pathogen-contaminated water resulting in both GI and non-GI illness was explored. Non-GI effects such as folliculitis and ear infections (van Asperen *et al.* 1995) were evaluated qualitatively to ensure that these risks were not overlooked in the assessment. GI effects associated with faecal-oral transmission are the primary effects evaluated in this study as these comprise the majority of reported cases associated with recreational exposure (Yoder *et al.* 2008) and is amenable to quantitative MRA techniques (Haas *et al.* 1999).

The primary elements of the CAWS MRA model are:

- Microbial Hazard Identification
- Exposure Assessment
- Dose-response Estimates
- Probability of GI illness (number of GI illnesses per CAWS location/year).

Following the hazard identification step, the exposure assessment step utilized population scale UAA survey data to estimate human exposures to pathogens based on activities and frequency of use expected in the CAWS. The dose-response step included literature review of the infectivity dose-response and the risk of illness from a given pathogen. The final step, risk characterization, used Monte Carlo methods to combine the results of the recreational exposures, dose-response and pathogen concentrations as the input for simulations in the model.

The CAWS microbiology data collection for this study included 125 samples: 75 dry weather and 50 wet weather samples collected at the North Side, Stickney and Calumet waterways, including upstream, downstream and final effluent samples. The description of the sampling locations (Figure 1) and the analyses of the microbiology data are presented by Rijal *et al.* (2009). The study provides microbiological survey of the CAWS and the WRP final effluents under dry and wet weather conditions. The assessment included quantification of classical faecal indicators such as *E. coli*, enterococci, FC, bacterial pathogens (*Salmonella* spp., *Pseudomonas aeruginosa*), protozoa (*Giardia* spp. and *Cryptosporidium* spp.) as well as viruses (enteric virus, adenovirus and norovirus). The survey results indicated that wet weather conditions had a higher frequency of detection of indicators and pathogens than dry weather conditions. It was concluded

that despite elevated levels of faecal indicator bacteria, the concentrations of actual pathogenic microorganisms in the CAWS are low during dry weather conditions, and that during wet weather events, the CSOs and tributary discharge contribute a significant microbial load to the CAWS. The actual measured pathogen concentrations from the Rijal *et al.* (2009) study were integrated into an MRA framework to evaluate the impact of continuing the current practice of discharging secondary treated but not disinfected effluents from the District's three WRPs to the CAWS. The current study focuses on determining overall health risks associated with the incidental contact recreational use of the CAWS.

Probabilistic analysis

A probabilistic approach was selected to evaluate the risk of GI illness for the designated recreational users of the CAWS. Probabilistic risk assessment utilized input distributions, rather than point estimates, to better represent the variability and uncertainty that exist for each input parameter. Thus, instead of using one value for exposure duration, water consumption or pathogen concentration, a range of possible values (or more correctly, a probability density function) is used. This is a more precise reflection of actual populations and results in a more accurate prediction of potential risk. The probabilistic approach (one-dimensional, based on both variability and uncertainty) selected for this risk impact analysis is Monte Carlo simulation using Crystal Ball[®] Pro software operating on a personal computer (Jaidi *et al.* 2009).

The analysis uses randomly selected numbers from within defined distributions (e.g. pathogen concentrations, exposure duration and ingestion rate) and selected equations to generate information in the form of risk distributions. (A fixed value was selected to begin the random number generation (123, 457). By using the same seed value within the Crystal Ball[®] Pro software, the same sequence of random numbers can be replicated.) Input distributions were sampled using Latin Hypercube sampling techniques to ensure equal representation of all parts of the input distributions. For each simulation, a hypothetical recreational user (receptor) was created with randomly assigned exposure duration and dose using underlying exposure distributions and the risks for the individual receptor was computed. The process was repeated one million times (i.e. the probability for a recreator to

become ill was examined by simulating one million recreational encounters) and the outcome of the infection was tracked for each simulation. The probability of developing GI illness was computed by comparing the ingested dose with the potential of each pathogen to produce illness at that dose (Geosyntec 2008). The probabilistic analysis proceeded using the following sequence:

1. Determine the weather-influenced waterway data set for microbial concentration based on the frequency of that type of weather in the recreational season.
2. Bootstrap sample a representative microbial exposure point concentration from the appropriate data set (select the pathogen concentration for the individual recreating on the day of exposure).
3. Select an individual's recreation type (canoeing, fishing or boating).
4. Select that individual's exposure duration (based on recreator type).
5. Select that individual's ingestion rate (based on recreator type).
6. Develop a dose for that individual (intake \times duration \times concentration).
7. Determine that individual's infection/illness.

Using this process, the various possible outcomes (risk levels) and the likelihood of achieving each outcome (percentages of the population protected at each forecasted risk level) were determined. From this, a projected risk distribution was derived for each waterway segment where use and pathogen concentrations were determined. Finally, the contribution of each pathogen to the total risk was computed.

RESULTS AND DISCUSSION

CAWS microbial hazard identification

The potential hazards (i.e. pathogens) in CAWS waters included in the study were associated with the following three general groups of microorganisms:

- Bacteria pathogenic *E. coli* (estimated), *Salmonella* spp., *P. aeruginosa*
- Protozoa *Giardia* cysts, *Cryptosporidium* oocysts
- Viruses adenovirus, enterovirus, norovirus

The microorganisms selected for the study were identified by Mead *et al.* (1999) and used in the MRA framework by Water Environment Research Foundation (WERF 2004). These pathogens have been identified as 'potential pathogens' in this study. In addition, indicator microorganisms (faecal coliform, *E. coli*, enterococci) typically present in the faeces of humans and other warm-blooded animals were included in the study as indicators of faecal pollution (Rijal *et al.* 2009). The summary of actual pathogen concentrations collected over dry and wet weather conditions in the CAWS is described in Table 1. During dry weather, pathogens (*Salmonella* spp., enteric viruses, adenovirus, norovirus, *Giardia* spp. and *Cryptosporidium* spp.) were present in low numbers. *P. aeruginosa* levels in the outfall samples were either lower or equivalent to the CAWS. The wet weather samples had a higher frequency of pathogen detection compared to dry weather samples. The *Salmonella* results had statistically insignificant detections; moreover, the low concentrations in the upstream and downstream samples were similar during wet weather conditions at the North Side, Stickney and Calumet segments of the CAWS. The vast majority of human cases of salmonellosis are acquired by ingestion of faecal-contaminated food or drinking water, with cases more common in the warmer months of the year (Maier *et al.* 2000). Person-to-person transmission of *Salmonella* occurs when a carrier's faeces, unwashed from one's hands, contaminates food during preparation or through direct contact with another person.

Most *E. coli* measured in the CAWS are not pathogenic; therefore, an assumption was required to adjust the reported *E. coli* concentration to account for the fraction of pathogenic organisms. Limited data exist to estimate the proportion of pathogenic *E. coli* in recreational waters. Detection frequency of the enterohaemorrhagic strain O157:H7 in cattle hides or faeces has been reported to vary between 0.2 and 30% (Galland *et al.* 2001; O'Brien *et al.* 2005). However, the absolute proportion of this pathogenic strain to all *E. coli*, even within cattle, is unknown. A survey of *E. coli* strains in the Calumet River is perhaps the best resource for establishing the proportion of pathogenic *E. coli* in the CAWS (Peruski 2005). This study was conducted for both wet and dry weather conditions. Results of the study found that 2.7% of the *E. coli* were human and animal pathogenic strains and 0.5% of the total *E. coli* were human pathogenic strains. Similar results were observed in both dry and wet weather

Table 1 | Summary of the actual and estimated¹ pathogen concentration ranges during dry and wet weather conditions used for MRA

Pathogens	North Side		Stickney		Calumet	
	Dry	Wet	Dry	Wet	Dry	Wet
<i>E. coli</i> ¹ (cfu/100 mL)	<1–1,350	324–1,377	<1–1,431	54–12,960	<1–2,700	<5.4–4,590
<i>P. aeruginosa</i> ² (cfu/100 mL)	<100–27,700	800–8,400	<10–14,600	200–75,000	<10–5,300	1,300–28,000
<i>Salmonella</i> spp.(MPN/100mL)	<1–2.2	0.54–33.4	<1–1.38	0.14–20.0	<1–0.45	0.064–20.5
<i>Giardia</i> ³ (cysts/L)	<0.1–4.6	<0.3–49.5	<0.2–4.9	<0.2–5.4	<0.1–2.2	<0.2–8.5
<i>Cryptosporidium</i> ³ (oocysts/L)	<0.1–<1.0	<0.2–1.6	<0.1–0.6	<0.2–0.8	<0.1–0.5	<0.2–6.3
Enteric virus ⁴ (MPN/L)	<0.01–0.247	<0.01–0.28	<0.01–0.0325	<0.01–0.63	<0.01–0.013	<0.01–0.85
Adenovirus ⁴ (PCR MPN/L)	<0.01–2.56	<0.01–28.90	<0.01–1.17	<0.01–15.6	<0.01–0.16	<0.01–>32.8
Norovirus ⁴ (PCR MPN/L)	<0.01–350 ⁵	<0.06–39.3	<0.01–5.11	<0.06–57	<0.01–7.8	<0.058–6.5

¹Estimated pathogenic *E. coli* concentrations = 2.7% of the total measured *E. coli* (Peruski 2005).

²Not included for GI illness MRA.

³Total concentrations include viable and non-viable cysts or oocysts.

⁴300 L of CAWS samples filtered and approximately 100-L samples were filtered at the final effluent outfall.

⁵Of the five samples, only one sample resulted in a high MPN value. The reduced precision of the analysis was mainly due to re-assay difficulties; therefore it is likely an artefact and appears to be an outlier.

events. As a conservative estimate, a factor of 2.7% was selected for the fraction of pathogenic *E. coli* in the CAWS. This value likely overestimates the true fraction of human pathogenic organisms; therefore, a single dose-response parameter that excludes the more infectious and less frequently encountered strains was employed to develop risk estimates.

Giardia and *Cryptosporidium* enumeration included both viable and non-viable cysts and total and infectious oocysts in the CAWS (Rijal et al. 2009). Only viable cysts and infectious oocysts are capable of causing illness; therefore, an estimate of the number of viable cysts and oocysts is required for use in risk assessment. Concentrations of oocysts and cysts across all samples were generally very low; as few as two, if any, detected in each sample analysed. The precision of the viability assay is diminished because of the low frequency of detection. For example, consider a sample with one cyst detected. In this case, the protozoa is either viable or not (100% viable or 0% viable). If this one cyst is viable, then the risk assessment may be biased high. If the one cyst is non-viable, then the risk assessment may be biased low. To better estimate viability over a larger data set, a WRP-wide viability value was generated and applied to the total number of cysts and oocysts for each sample within that WRP segment. Dry and wet weather viability values were generated by pooling the total viable and non-viable cysts and oocysts in both instream and outfall samples from each WRP segment.

For dry weather CAWS samples, no infectious oocysts were detected. Overall, the combined wet and dry weather percentage of infectious foci is estimated to be approximately 2.40% (3 of 125 samples [75 dry weather and 50 wet weather samples] contained infectious foci). For *Giardia* cysts, the dry weather viability values used were 26, 21 and 10% for the North Side, Stickney and Calumet WRPs, respectively. The wet weather viability values were higher; 49, 47 and 10% for the North Side, Stickney and Calumet WRPs, respectively.

The virological results indicate that in dry weather, a relatively small number of samples had detectable concentrations of culturable enteric viruses. The percentage of enteric viruses, adenovirus and norovirus detections during dry weather was lower compared to wet weather detections. The average adenovirus and norovirus concentrations were higher during reported pumping station (CSO) discharge events (Rijal et al. 2009).

Exposure assessment

Risk assessment exposure inputs were drawn extensively from the UAA recreational use survey on the types and frequency of recreational exposure expected in the CAWS (CDM 2004; Geosyntec 2008). The incidental contact recreational uses identified in the UAA report were divided into relatively high (canoeing), medium (fishing) and low

(pleasure boating) exposure activities. Based on the receptor use grouping and survey results, the proportion of users in each of the three exposure groups was calculated within each waterway (Table 2). Pleasure boating is the largest use of the CAWS. Fishing is the next most popular activity. Canoeing and kayaking are popular near the North Side location, but not on any other waterway segment. Swimming was not observed in any of the waterways.

Exposure parameters were developed as distributional parameters for each receptor scenario for inputs to the exposure model. These parameters include incidental ingestion rates and exposure duration. There are no direct studies that have quantified the amount of water that participants in incidental contact water sports such as canoeing, fishing and boating may ingest. However, studies have reported observed illnesses in canoeists and kayakers boating in water with measured microbial contamination (Fewtrell *et al.* 1992, 1994). Fewtrell *et al.* (1994) reports that studies of rowing and marathon canoeists showed approximately 8% of canoeists at freshwater sites reported capsizing and approximately 16% of rowers reported water ingestion. These studies indicated that these activities are likely to involve some degree of incidental water ingestion. Water ingestion rates found in the literature were primarily from full contact swimming studies which ranged from 30 mL/hr (Crabtree *et al.* 1997; Van Heerden *et al.* 2005) to 50 mL/event (US EPA 1989; Steyn *et al.* 2004). Dufour *et al.* (2006) reported that non-adults swallow an average amount of 37 mL/event compared to 16 mL/event by an adult. These values are based on a swimming scenario which would result in ingesting significantly more water than one might ingest through incidental contact activities. Only in instances in which a canoeist might capsize could water be ingested at an appreciable rate. A value of 10 mL/event was reported for the accidental gulping of water during activities such as cleaning,

Table 2 | Proportion of recreational activities in CAWS locations

Recreational activity	Waterway		
	North Side	Calumet	Stickney
Canoeing	20.2%	1.2%	0.5%
Fishing	72.2%	28.4%	47%
Pleasure boating	7.6%	70.4%	52.5%

laundry, fishing and agricultural/horticultural irrigation (Genthe & Rodda 1999; Medema *et al.* 2001).

Figure 2 and Table 3 present a summary of the incidental ingestion rates. For canoeists, incidental ingestion was assumed to follow a log-normal distribution with a mean of 5 and a standard deviation of 5 [LN (5, 5)]. In this case, the median (50th percentile) water ingestion rate was 7.52 mL/hr and the maximum (100th percentile) was 34 mL/hr, within the range reported for full contact swimming. For the 90th to 100th percentile, ingestion rates ranged from 14 to 34 mL/hr, which implies that 10% of the population may be exposed to water ingestion rates approaching those observed in swimming or accidental gulping. This is consistent with the observation in the Fewtrell *et al.* (1994) study in which 8% of canoeists reported capsizing, an event that may result in ingestion rates similar to gulping or swimming. To best simulate the reduced water ingestion rates associated with incidental contact use of the CAWS, time-dependent ingestion rates were used to

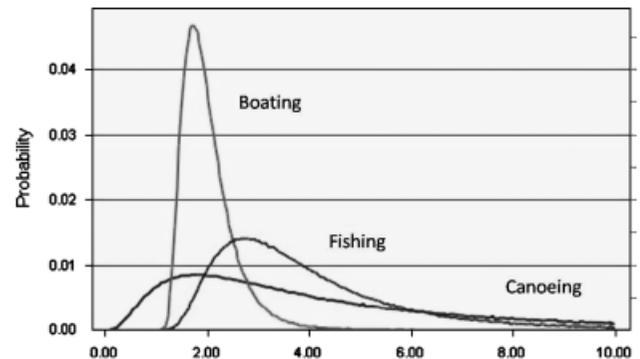


Figure 2 | Water ingestion rate (mL/hr).

Table 3 | Incidental ingestion rate percentiles

Percentiles	Boating (mL/hr)	Fishing (mL/hr)	Canoeing (mL/hr)
10%	1.49	2.98	5.21
25%	1.65	3.30	6.02
50%	1.90	3.79	7.52
75%	2.23	4.47	10.15
90%	2.64	5.28	14.16
95%	2.95	5.89	17.84
97.5%	3.26	6.51	21.99
100%	7.43	22.13	34.00

account for background intakes associated with inhalation, coupled with a variable term developed from a log-normal distribution. Log-normal distributions arise from a multiplicative process and tend to provide good representation of exposure parameters based on natural phenomenon (Ott 1995).

Incidental ingestion rates for fishermen were assumed to follow a log-normal distribution with a mean of 3 and a standard deviation of 2 [LN (3, 2)]. The incidental ingestion rate for a pleasure boating group was assumed to follow a log-normal distribution with a mean of 1 and a standard deviation of 0.5 [LN(1, 0.5)]. A fixed intake term of 1 mL/hr was added to the log-normal intake rate for both boaters and fishermen to account for background intake associated with ingestion of inhaled droplets.

For the exposure duration values based on information in the use survey (CDM 2004), it was assumed that for a canoeist, the minimum time in the CAWS is 1 hour and the likeliest duration is 2.6 hours (Figure 3). For pleasure boating and fishing, it was assumed that the likeliest time on the water would be approximately 3 to 4 hours. For boaters, it was assumed that the maximum time on the water would be 8 hours and for fishing the maximum time was assumed to be shorter than 6 hours. These values were used to construct triangular distributions for inputs in the risk assessment (Figure 3).

Dose-response estimates

The exponential and beta-Poisson dose-response models describing the relationship between the dose of a pathogenic organism and the probability of infection or illness in exposed

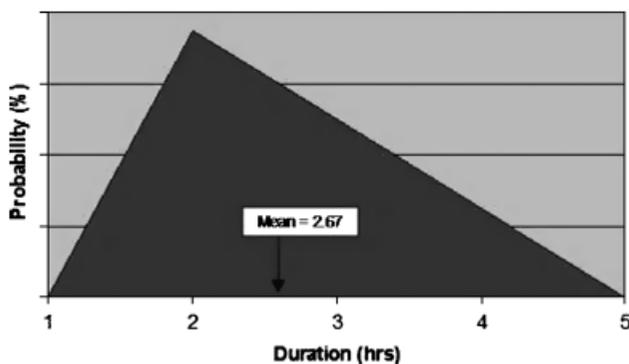


Figure 3 | Duration distribution for canoeists.

persons were derived from the literature (Rose et al. 1991; Teunis et al. 1996; Haas et al. 1999). In the exponential model, it is assumed that all of the ingested organisms have the same probability ($1/k$) of causing an infection. The dose ingested is assumed to be Poisson distributed with a mean of D organisms per portion (Haas et al. 1999). The probability of infection given a dose (D) is:

$$P(D) = 1 - \exp(-1/k \times D) \quad (1)$$

where $P(D)$ is the probability of infection and $1/k$ is the parameter of the exponential relationship. The median infectious dose (N_{50} ; dose of an organism resulting in a 50% probability of infection) for an exponential dose-response relationship is derived from equation 1 and given by:

$$N_{50} = \ln(0.5)/(-k) \quad (2)$$

In the beta-Poisson model, heterogeneity in the organism/host interaction is introduced and k is assumed to follow a beta-Poisson distribution (Haas et al. 1999). The resulting model is more complex but can be approximated under the assumption that β is much larger than both α and 1 so that the probability of infection given a dose (D) is:

$$P(D) = 1 - \left(1 + \left(\frac{D}{\beta}\right)\right)^{-\alpha} \quad (3)$$

where $P(D)$ is the probability of infection, D is the dose ingested and α/β are the dose-response parameters for the beta-Poisson model.

This model is the current state-of-the-science for characterizing dose-response relationships where the probability of host-pathogen survival is governed by a probability distribution (Teunis et al. 1996; Haas et al. 1999). The median infectious dose (N_{50}) under a beta-Poisson model is derived from equation 3 and given by:

$$N_{50} = \frac{\beta}{\left(2^{(1/\alpha)} - 1\right)} \quad (4)$$

A summary of the dose-response parameters used is provided in Table 4. Of the enteric viruses, dose-response information is available for poliovirus I, echovirus 12 and Coxsackie virus (Haas et al. 1999). Each of these viruses fits an exponential dose-response model with exponential para-

meters (k) in a narrow range from 69.1 to 109.9 (Haas *et al.* 1999). Dose-response information is not available for adenovirus related GI illness. The dose-response for echovirus 12 ($k = 78.3$) was selected as a surrogate for total enteric viruses and adenovirus with an infectivity in the middle of this range. The selected value is within the range of values used in the WERF (2004) biosolids study. No human studies are available to derive a dose-response relationship for norovirus. Based on rotavirus dose-response experiments in human volunteers, the dose-response model for rotavirus fits a beta-Poisson model (Ward *et al.* 1986). The median infectious dose (N_{50}) of 6.17 with an α value of 0.2531 was used for norovirus in this study.

Microbial exposure point concentrations during dry and wet weather conditions

Individuals recreating in the CAWS may encounter variability in pathogen concentration over both time and space. Receptors travelling in watercraft may be exposed to pathogens over a large stretch of the CAWS. Even receptors fishing from the bank may encounter waterway pathogen concentrations that vary over the course of the exposure duration. The pathogen concentration term used to estimate risk reflects the actual pathogen concentrations encountered over the course of the exposure in the CAWS.

The dry weather sampling results and risk characterization were developed by segregating data based on location

relative to the WRPs (i.e. upstream and downstream). All upstream and downstream samples were collected from locations at 15 waterway widths (within 2 miles) from the WRP outfalls. The pathogen concentrations during the dry weather conditions were low from both upstream and downstream locations, with most pathogens having slightly higher downstream concentrations (Rijal *et al.* 2009). However, the relative differences between upstream and downstream pathogen concentrations were small in comparison to concentration data between dry and wet weather conditions (Table 1).

Wet weather samples were collected from locations both directly upstream and downstream, and additionally along the entire length of each waterway segment downstream of the North Side, Stickney and Calumet WRPs. In contrast to the dry weather conditions where the WRP effluents constitute the major flow and pathogen input to the CAWS (more than 70% of the flow), wet weather inputs (CSO overflows, pumping station discharge points and stormwater discharges) are widely distributed along the waterway. The larger spatial coverage of the wet weather sampling reduces the uncertainty in the waterway pathogen concentration in areas distant from the WRP effluent discharge where recreational use is most likely to occur. In addition, recreational users may be exposed to pathogens over long stretches of the waterway through watercraft use. For this assessment, recreational use is assumed to occur along the entire WRP waterway segment. The pathogen concentration detected along the waterway is the best representation of the exposure that a receptor might encounter. The combined upstream and downstream samples pathogen data were used for characterizing overall risks. For each of these groups, the variability in pathogen concentration was captured by bootstrap sampling from the entire WRP waterway segment data set. Outfall data were combined as an arithmetic average of all outfall samples for each WRP.

Risks were estimated for recreational users participating in activities involving different levels of exposure in dry, wet or a combination of weather events over the course of a recreational year. Concentrations of pathogens in the waterway were selected for each simulation from the entire data set of dry and wet weather samples collected. The proportion of dry and wet weather samples utilized were weighted to account for the proportion of dry and wet weather days in a typical Chicago recreational season (Geosyntec 2008). The

Table 4 | Summary of dose-response parameters used to relate risk of GI illness to dose for the seven potential pathogens

Pathogen	Beta-Poisson		Exponential (k)
	(α)	N_{50}	
Total enteric viruses ¹			78.3
Adenovirus ¹			78.3
Norovirus ²	0.2531	6.17	
<i>Cryptosporidium</i> ⁵			238
<i>Giardia</i> ⁵			50.5
<i>Salmonella</i> spp. ³	0.3126	23600	
<i>Escherichia coli</i> ⁵	0.1748	2.55×10^6	

¹The dose-response for echovirus 12 was used as a surrogate.

²The dose-response for rotavirus was used as a surrogate.

³Dose-response relationships taken from Rose *et al.* (1991) and Haas *et al.* (1999).

frequency of dry and wet weather days was established by reviewing meteorological data from the greater Chicago area as measured at the District monitoring station at Stickney for the 2005–2006 recreational seasons (Table 5). For the purpose of this analysis, a dry weather day was defined as no rain events in the preceding 72 hours. By this criterion, only 55 days (about 15%) of dry weather conditions occur each recreation season in the CAWS. Approximately 146 days (about 40%) of wet weather/CSO conditions occur each recreation season in the CAWS.

The wet weather impact on the CAWS has been studied, which demonstrates that the North Side and Calumet WRPs are not the only significant sources of faecal coliform bacteria to the CAWS. During wet weather, even light rainfall periods with no CSOs, the CAWS receives non-point bacterial loads that elevate FC concentrations in the CAWS to levels much higher than are observed during dry weather. Also, during dry weather periods, lingering effects of wet weather, as well as tributary loads, maintain elevated levels of FC in the CAWS (District 2007). These results indicate that even if effluent disinfection were completely effective at reducing FC, the microbiological water quality downstream of the District WRPs would still be much higher than the effluent limitation of 400 FC cfu/100 mL a great deal of the time (District 2007). This conclusion was further supported by the microbiological characterization study of the CAWS for FC and pathogens, which concluded that despite elevated levels of FC, the concentrations of actual pathogenic microorganisms in the CAWS are low during dry weather conditions and that during wet weather events, the CSOs contribute a significant microbial load to the CAWS (Rijal et al. 2009). It is evident that the

pathogen concentrations are low in the District's WRP non-disinfected secondary effluent and the microbial quality of the CAWS is impacted by wet weather and CSO events.

Typically, dry weather periods allow any residual pathogens from CSOs or other wet weather inputs to attenuate. For this study, the dry weather sampling data were reflective of the effects of WRP effluent on the pathogen concentrations in the waterway with very little impact from residual wet weather effects. There were no samples collected in intervening periods between the wet weather and dry weather sampling events. However, these days represent a large portion of the recreational year and estimates of the concentration in the waterway on days between wet and dry weather conditions are an important consideration in the risk assessment. Estimates of pathogen concentrations in the days following a wet weather event were based on modelling the attenuation of pathogens from the wet weather data through the following two days.

The attenuation of pathogens through natural processes tends to follow an exponential decay curve (Haas et al. 1999). The general exponential decay function is described in Figure 4.

$$Conc(x) = \exp(-t \times \beta) \times Conc(i)$$

where:

$Conc(x)$ = pathogen concentration at time x ,

t = time after wet weather event,

i = initial time (immediately following end of wet weather period),

β = decay constant (assumed = 1)

Selection of an exponential decay constant (β) was based on a parsimonious fit to the data for organisms detected in both wet and dry sampling events. Using a $\beta = 1$ with the geometric mean of the wet weather sampling data tends to produce values at the 72 hour time frame that approximate the

Table 5 | Proportion of weather days in recreational year¹

Weather conditions	Proportion of season
Wet weather	
Wet/CSO events	0.40
24 hrs post wet weather	0.30
48 hrs post wet weather	0.15
Dry weather	
> 48 hrs post wet weather	0.15

¹Recreational year includes dates from April to November; data used to construct proportions based on District CSO and rain gauge records for the 2006 recreational year.

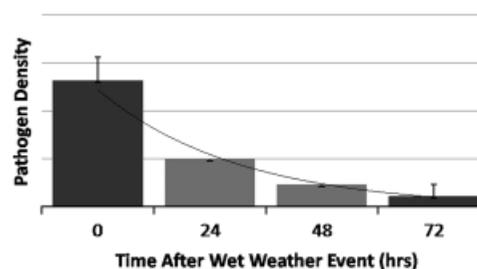


Figure 4 | Estimated pathogen concentration between wet and dry sampling events.

geometric mean of the concentrations seen in the dry weather sampling. However, in reality, it is demonstrated that the FC bacteria level remains much higher even 72 hours past the wet weather event (District 2007). During dry weather periods, lingering effects of wet weather as well as tributary loads maintain elevated levels of FC in the CAWS. While organism-specific attenuation factors could be developed, the variability observed suggests that the uncertainty in these values would be large. Therefore, a simple exponential decay was selected as the model to estimate the pathogen concentration at 24- and 48-hour intervals after wet weather events. A pseudo-data set was constructed using each of the original wet weather data points to develop a 24- and 48-hour post-wet weather data set (Figure 4). The results of the statistical analysis of the trend in FC concentrations of the North Side and Calumet WRPs showed no significant reduction rate ($p > 0.05$) for the 24- and 48-hour period following a heavy rain event (District 2007). This confirms that wet weather effects linger well after the rainfall ends (Manache & Melching 2005; Manache *et al.* 2007; Alp & Melching 2009).

Microbial risks characterization – gastrointestinal illness

Results from the risk simulations were converted to GI illness rates per 1000 exposures. Wet weather and dry weather simulations provided a range of risks given this important variable. Overall risks developed for the combined dry and wet weather data set for the North Side and Stickney waterway segments indicate that the majority of predicted illnesses were the result of concentrations of viruses, *E. coli* and *Giardia* (Geosyntec 2008). For the Calumet waterway, the risks are generally lower with multiple organisms contributing to the overall risk. Risk calculations were developed for all users, in proportion to the frequency of use, for each waterway segment that spans the range of exposures reported in the UAA survey. The proportion that specific recreational users contribute to the expected GI illness is shown in Table 6.

The recreational activity which results in the greatest number of affected users depends on the proportion of users engaged in that activity, the relative level of exposure resulting from the use and the pathogen load in that waterway segment. For example, in the North Side segment, 33.7% of the illnesses are predicted to result from canoeing, but canoe-

Table 6 | Proportion of recreational user type contributing to gastrointestinal expected illnesses with no effluent disinfection¹

Recreational use	Waterway		
	North Side	Stickney	Calumet
Canoeing	33.7%	8.3%	2.9%
Fishing	58.7%	53.1%	38.2%
Boating	7.6%	38.5%	58.8%

¹Based on combined waterway samples (upstream and downstream) over the entire recreational season.

ing accounts for only 20% of the users in the North Side waterway. In the Stickney and Calumet segments, the predicted illnesses were predominately from fishing and boating due to the low frequency of canoeists in these waterway segments.

Under dry and wet weather conditions, estimated GI illness rates were found to range from 0.36 to 2.78 cases/1000 events upstream and downstream in the North Side WRP in the NSC/NBCR, from 1.28 to 2.34 cases/1000 events above and below the Stickney WRP in the South Branch Chicago River/CSSC and from 0.10 to 0.36 cases/1000 events upstream and downstream from the Calumet WRP in the Little Calumet River/CSC (Table 7). The total expected illnesses per 1000 exposures during combined weather conditions ranged from 0.21 in the Calumet to 1.74 in the Stickney waterway locations.

To further characterize the risk, the risks calculated were stratified for all users in proportion to the frequency of use for each waterway segment (Table 8). The predicted GI illness per 1000 exposures during combined dry/wet weather conditions from canoeing was 2.45 in the North Side segment, 3.19 in the Stickney segment and 0.52 in the Calumet segment. The predicted illness per 1000 exposures during combined dry/wet weather conditions from fishing was 1.42 in the North Side segment, 1.90 in the Stickney segment and 0.31 in the Calumet segment. Pleasure boating predicted the lowest illness rate, which ranged from 0.14 in the Calumet segment to 1.05 in the Stickney segment.

Effect of effluent disinfection on CAWS microbial risks

Currently, there are no site-specific data available to determine the effectiveness of WRP effluent disinfection on CAWS

Table 7 | Total expected GI illnesses per 1,000 exposures using different estimates of pathogen concentrations with no effluent disinfection¹

Exposure input ²	Waterway		
	North Side	Stickney	Calumet
Dry weather	0.36	1.28	0.10
Wet weather	2.78	2.34	0.36
Combined weather samples	1.55	1.77	0.21

¹Includes all primary gastrointestinal illnesses from *E. coli*, *Salmonella* spp., total enteric viruses, adenoviruses, *Giardia* and *Cryptosporidium* expected from the waterway exposures.

²Waterway concentration inputs for the simulations were randomly selected (bootstrap sampled) from the microbial sample data sets.

pathogen concentrations. An estimate of this effect, however, was derived using the dry and wet weather sampling data along with the published technical literature on pathogen reduction rates under various disinfection techniques. To estimate the effect of disinfection of the effluent from the District WRPs on microbial risk, the waterway pathogen concentrations were estimated by combining the waterway concentrations associated with wet weather conditions with the estimated residual post-disinfection dry weather concentrations for the respective pathogens. Disinfection efficiencies used in this approach are presented in Table 9 (Geosyntec 2008). Under dry weather conditions, the WRP effluent is the major microbial source to the CAWS while in wet weather conditions, non-WRP inputs are a significant source of microbial load to the waterway. Since the WRP effluent pathogen loads are similar in both dry and wet weather conditions, the dry weather sampling data were used to estimate the waterway load that could be affected by disinfection. Wet weather sampling data were assumed to encompass both WRP effluent loading (attenuated by disinfections) and non-point discharges to the waterway (e.g. CSOs, pumping stations, stormwater outfalls).

Table 8 | Stratified risk estimates – estimated illness rates assuming single recreational use with no effluent disinfection

Recreational use	Illnesses per 1,000 exposures for combined wet and dry weather samples		
	North Side	Stickney	Calumet
Canoeing	2.45	3.19	0.52
Fishing	1.42	1.90	0.31
Pleasure boating	0.66	1.05	0.14

Table 9 | Fold attenuation of pathogen concentration by various treatment methods

Pathogen	Ozonation	UV Irradiation	Chlorination
<i>E. coli</i> (pathogenic)	10,000	10,000	10,000
<i>P. aeruginosa</i>	100	10,000	10,000
<i>Salmonella</i>	10,000	1000 ²	1000 ²
<i>Enterococcus</i>	100 ²	100 ²	100 ²
<i>Cryptosporidium</i>	17.0 ¹	1000	5.9 ¹
<i>Giardia</i>	114.8 ¹	100	3.2 ¹
Enteric virus	100,000	11.7 ¹	100,000
<i>Calicivirus</i>	100	10,000	100
Adenovirus	100 ²	100 ¹	100 ²

¹Geometric mean of data (range) (Geosyntec 2008).

²Estimate based on professional judgment.

Donovan et al. (2008) evaluated the risks from swimming or wading activities for recreational and homeless persons exposed to recreational waters in the Passaic River. The authors found elevated risks for all pathways attributed to CSO impacts that result in elevated levels of bacteria, viruses and protozoa.

Graczyk et al. (2000) showed that fishing in urban estuaries with CSO inputs may expose recreators to a significant pathogen-related risk. Risks were assessed by measuring *Cryptosporidium* on the hands of the recreators, presumably transferred by handling fish or rinsing their hands in contaminated water. Raw sewage impacts under CSO conditions can release extremely high levels of coliform bacteria and significant levels of virus and protozoa to the receiving water body (US EPA 2005). For example, *Giardia* has been measured in untreated wastewater at levels of 200,000 cysts/L and *Cryptosporidium* has been measured at 13,000 oocysts/L (US EPA 2004). It should be noted that the levels of *Giardia* and *Cryptosporidium* in the CAWS were significantly lower, ranging from <0.1 to <50 cysts/L, and <0.1 to <10 oocysts/L, respectively. Wet weather conditions without CSOs have also been reported to contribute to elevated levels of microorganisms. Studies of urban stormwater demonstrate high levels of indicator organisms with the presence of viruses and protozoa (Jiang et al. 2001). Even in conditions where no human or animal impacts are suspected, wet weather can influence microbial loads. A survey of pristine streams, uninfluenced by human or animal wastes, was evaluated under both wet and dry weather conditions (Tiefenthaler et al.

2008). Streams sampled in wet weather had significantly elevated levels of enterococci and faecal coliform (Tiefenthaler *et al.* 2008). Together these studies support the findings that wet weather events are related to elevated levels of indicator and pathogenic organisms (Rijal *et al.* 2009).

The estimated GI illness rates per 1000 exposure events were found to be reduced by UV irradiation from 1.55 to 1.32 below the North Side WRP; from 1.77 to 1.48 below the Stickney WRP; and from 0.21 to 0.17 below the Calumet WRP, respectively (Table 10). Similar rates of GI illness reductions were estimated for ozone and chlorination techniques.

Disinfection of the effluent outfall was predicted to result in a decrease in effluent pathogen loads but have a much lower effect on overall pathogen concentrations in the CAWS. Disinfection resulted in effluent pathogen risk emanating from the WRP outfalls decreasing from a low level to essentially zero but had little impact in the CAWS pathogen concentrations affected by wet weather conditions. These results suggest that disinfection of the WRP effluent will have little impact on the overall GI illness rates from recreational use of the CAWS.

According to WERF (2005), disinfection is warranted in situations where direct human contact in the immediate vicinity of an outfall is possible or where effluent is discharged to areas involving the production of human food. Disinfection is warranted in situations where its application leads to a reduction in the risk of disease transmission. As illustrated by post-disinfection regrowth of bacteria, relatively poor virucidal behaviour and the generation of persistent disinfection by-

products (DBP), it is not clear that wastewater disinfection always yields improved effluent or receiving water quality (WERF 2005). There is an uncertainty if disinfection designed to remove faecal indicators can be effective in the removal of pathogens and in the reduction of pathogen risks (Blatchley *et al.* 2007).

Non-gastrointestinal microbial risks

Pseudomonas aeruginosa is a pathogen that is not linked to GI illness. This pathogen has been linked to non-GI related recreational illness outbreaks involving dermal (folliculitis), eye and ear (otitis externa) infections (Cabelli *et al.* 1979; Seyfried & Cook 1984). For this reason, the levels of *P. aeruginosa* were evaluated under the sampling program for this risk assessment. There are no published dose-response relationships for *P. aeruginosa* to establish the expected illness level associated with any particular waterway concentration. Data from a four-year study developed a relationship between the concentration of *P. aeruginosa* in the bathing waters and the risk of ear infection (Ontario Ministry of the Environment 1984). The Ontario study estimated that when levels of *P. aeruginosa* exceed 10 cfu/100 mL in at least 25% of the seasonal samples, otitis externa may be expected to occur. The dermal pathway for estimating exposure due to ear and eye infections associated with contact by *P. aeruginosa* contaminated water is typically associated with full immersion activities. Since these types of activities are not permitted or designated uses of the CAWS, the incidence of ear and eye exposures are expected to be low.

In this study, a qualitative review of the wet and dry weather data was conducted for the relative risk from *P. aeruginosa* exposure. Comparisons between dry and wet *P. aeruginosa* concentrations at the three WRP segments are provided in Table 1. The wet weather levels are higher than those in the dry weather conditions. Perhaps more importantly, the outfall samples show lower levels of *P. aeruginosa* than the corresponding wet weather samples (Rijal *et al.* 2009). This suggests that the major inputs for *P. aeruginosa* in the waterways are sources other than the WRP effluent. It is important to note that *P. aeruginosa* is ubiquitous in US waters with both faecal and non-faecal sources. Approximately 10% of healthy North American adults are intestinal carriers of *P. aeruginosa*, resulting in concentrations in raw

Table 10 | Total expected primary illnesses per 1,000 exposures under combined dry and wet weather using different effluent disinfection techniques¹

	Waterway		
	North Side	Stickney	Calumet
No disinfection	1.55	1.77	0.21
UV irradiation	1.32	1.48	0.17
Ozone	1.45	1.65	0.19
Chlorination	1.43	1.63	0.19

¹Estimates based on geometric mean pathogen concentrations and central tendency estimates for exposure assumptions. Waterway pathogen concentrations were developed by the difference in wet and dry disinfected concentrations. Includes all primary GI from *E. coli*, *Salmonella*, total enteric viruses, adenoviruses, *Giardia* and *Cryptosporidium* expected from the waterway exposures

domestic sewage ranging from 10^5 to 10^6 cfu/100 mL (Canadian Ministry of Health and Welfare 1992). Another study measured *P. aeruginosa* in raw sewage as a level of 1800 cfu/mL, wastewater treatment effluent at 140 cfu/mL and canal and lake water at 10 cfu/mL (Dutka & Kwan 1977). In addition, *P. aeruginosa* levels in excess of 100 organisms/mL can be measured in waters receiving surface drainage from urban areas (Ontario Ministry of the Environment 1984). *P. aeruginosa* survives longer in waters than do coliforms (Lanyi et al. 1966) and has the ability to multiply in waters with low nutrient content (Canadian Ministry of Health and Welfare 1992).

Adenovirus subtypes 40 and 41 were selected and enumerated for this study. These subtypes are primarily associated with gastroenteritis and viral diarrhoea (Jiang 2006). However, there are other adenoviruses such as subtype 4 which cause nose, eye and respiratory infections (D'Angelo et al. 1979). An exponential model has been proposed for the respiratory adenovirus 4 with a k value of 2.397 (Hass et al. 1999). Therefore, the exposure to adenoviruses via inhalation was factored into the GI risk estimation.

Uncertainty and sensitivity analysis

Uncertainty in the risk estimates is an important part of the risk characterization. Assumptions used in the analysis may lead to an overestimation or underestimation of risk. A sensitivity analysis was conducted to identify the contribution of each input distribution to the variance of the resulting risk estimates. An alternative sensitivity evaluation is shown in Table 11. Illness rates for the North Side waterway segment are presented in cases where the incidental ingestion rate and exposure duration inputs varied by $\pm 25\%$. Increasing the intake assumptions leads to a 19% increase in estimated risk, while decreasing intake assumption results in a 27% decrease in estimated risk. The effects of changing the weather type from the combined wet and dry weather assessment to scenarios of 100% dry or 100% wet weather were evaluated.

Results from the sensitivity analysis indicate that the incidental ingestion rates and weather are the largest contributors to the North Side waterway segment. Recreational user type followed by incidental ingestion rate, exposure duration and weather contributes the most to the variance for the Stickney and Calumet waterway segments.

Table 11 | Parameter sensitivity analysis for North Side (illnesses per 1000 recreational users)

Input parameters	Input option		
	-25%	Baseline	+25%
Ingestion rate	1.11 (-28%) ¹	1.53	1.82 (+19%)
Exposure duration	1.11 (-28%)	1.53	1.82 (+19%)
Weather type	Dry	Baseline	Wet
	0.06 (-96%)	1.53	2.78 (+82%)

¹Relative percent increase or decrease from baseline illness rate.

While the pathogens that were selected for inclusion in the study included those that could be measured by EPA approved methods and that were judged most likely to produce GI illness, this study did not account for all pathogens that may be present in the CAWS recreational water (Yoder et al. 2008). The measured potential pathogen concentrations under dry weather conditions are limited to sampling locations near the WRPs and they were used as representative concentrations of the entire waterway downstream of the WRP. Under dry weather conditions, these concentrations may be biased high relative to concentrations at locations more distant from the WRP.

The measured concentrations of *E. coli* are assumed to represent the most virulent strain; the percentage of pathogenic *E. coli* was conservatively assumed to represent 2.7% of the total concentrations. For other organisms, such as adenovirus, all the organisms are assumed to represent the pathogenic strain leading to GI illness. This assumption may overestimate the illness associated with exposure to these organisms. Similarly, the viral assay used was not specific to the pathogenic virus in question and may also detect less pathogenic viral strains. Thus virus concentrations measured by this assay may overestimate viral risk.

Recreational use may be inversely correlated with wet weather. CAWS recreational use was assumed to occur randomly over the course of the recreational season. The majority of the illnesses were associated with wet weather events. If the frequency of exposure on wet weather days is lower than the overall recreation season daily average, then the resulting risk estimate may be biased high.

Risks from pathways other than ingestion were not included in this assessment. For example, risks associated with exposure to sediment or sand on the shoreline were excluded from the evaluation. This type of exposure is thought to be an important component of recreational illness for recreational activities near beaches (Mendes *et al.* 1997; Whitman *et al.* 2009).

CONCLUSIONS

Results of the risk assessment demonstrate that risks to incidental contact recreational users of the CAWS under various weather conditions and use scenarios are low and within the US EPA recommended risk limits for water contact exposure. The highest rates of GI illness were associated with recreational use on the Stickney and North Side waterway segments and the lowest GI illness rate was on the Calumet waterway segment. The GI illness rates were higher under wet weather conditions than under dry weather conditions. The results demonstrate that the expected GI illness rates for incidental contact use in the CAWS were all below the proposed US EPA limit of 8 illnesses per 1000 primary contact exposure events for freshwater recreational use including immersion/swimming activities.

The present study found pathogen loads in the CAWS and recreational user risks for GI illness associated primarily with wet weather inputs. These results are similar to other studies that have been performed to determine the risk of GI disease associated with pathogens in other waterway systems in the United States that found wet weather conditions to increase risk (Donovan *et al.* 2008). Wet weather and CSOs contribute elevated levels of bacteria, viruses and protozoa to receiving waters (Rijal *et al.* 2009). As a result of wet weather impact being the largest source of microbial pathogen load to the CAWS, this study determined that disinfecting the effluents of three major WRPs that discharge to the CAWS would result in an extremely small reduction in the aggregate recreation season risk to incidental contact recreators.

The MRA is inherently microbial agent specific and can only be based on waterborne pathogens for which dose response data are currently available (Rose *et al.* 1991; Teunis *et al.* 1996; Haas *et al.* 1999). In this study, pathogens representative of those present in the wastewater that are of

public health concern were selected to minimize the potential likelihood of underestimation of the risk. This study did not address the cumulative effects of exposure to multiple pathogens; however, the results of MRA were based on conservative assumptions. Factors such as person-person transmission, immunity, symptomatic infection and/or incubation period were not included in the MRA. The impact of protective immunity in the MRA is important. Exclusion of these parameters may result in substantial overestimation of health risk. In addition, the wet weather events make up 40% of the total recreational days and result in relatively high microbial concentrations in the CAWS. The risk assessment model assumes that recreation occurs on these days just as it would on the dry days (including 24 hours, 48 hours and > 72 hours post wet weather). It is not likely that incidental contact recreation is as frequent on these days as would be observed on dry days. This assumption can significantly overestimate the risk.

The MRA model developed in this study is valuable for its ability to integrate recreational use survey data, weather information, pathogen concentrations and dose-response data in estimating health risks to incidental contact recreating population in an urban waterway such as CAWS. There are models available to estimate water quality parameters such as dissolved oxygen (DO) and FC in the CAWS (Manache & Melching 2005; Manache *et al.* 2007). However, FC is an indicator bacterium and Rijal *et al.* (2009) found poor correlation between FC and pathogen concentrations in the CAWS. This may be due to low pathogen concentrations in secondary treated effluent from the District's WRPs and the difference in pathogen decay rates in the environment. The MRA would be improved if the model could be coupled with an advanced pathogen transport and hydrodynamic flow model to simulate pathogen concentrations throughout the CAWS (Chau & Jin 2002; Chau & Jiang 2004; Alp & Melching 2009; Mahajan *et al.* 2009; Pai *et al.* 2009) during each recreational event. Such a model would allow estimation of pathogen concentrations at locations and times when no actual sampling data are available, thereby improving dose assessment. Additional sensitivity analysis using variable expected concentrations could allow for a more complete evaluation of human health effects in the CAWS under dry and wet weather flow conditions.

This is the first study to assess the health risks associated with incidental contact recreational use of a man-made urban

river system. The Chicago Health, Environmental Exposure and Recreation Study (CHEERS), a companion epidemiological study, is currently being conducted to determine actual rates of acute GI and non-GI illness attributable to CAWS recreation. The study will characterize the relationship between concentrations of microbes in the CAWS and rates of illness among recreators and identify pathogens responsible for acute infections among recreators. The results of the CHEERS study will be used to verify the results of this risk assessment. We believe this model is adaptable for use in assessing risk in other waterways where fundamental input data are available.

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