Risk of Gastrointestinal Disease Associated with Exposure to Pathogens in the Water of the Lower Passaic River[∇]

Ellen Donovan,[1]* Ken Unice,[2] Jennifer D. Roberts,[3] Mark Harris,[4] and Brent Finley[1]

ChemRisk, 25 Jessie Street, Suite 1800, San Francisco, California 94105[1]; ChemRisk, 20 Stanwix Street, Suite 505, Pittsburgh, Pennsylvania 15222[2]; Exponent, 85 Hansen Court, Suite 100, Chicago, Illinois 60191[3]; and ChemRisk, 10375 Richmond Avenue, Suite 350, Houston, Texas 77042[4]

During precipitation events, untreated human sewage is often intentionally discharged to surface water bodies via combined sewer overflow (CSO) systems in order to avoid overloading wastewater treatment plants. The purpose of this analysis was to evaluate the risk of pathogen-related disease associated with CSO discharges into the Lower Passaic River. Concentrations of fecal coliform, total coliform, fecal *Streptococcus*, and fecal *Enterococcus* bacteria were measured at six river locations on six different days in 2003 ($n = 36$). In addition, water samples ($n = 2$) were collected directly from and in the immediate vicinity of a discharging CSO in Newark, NJ. These samples were analyzed for fecal coliforms, total coliforms, fecal *Streptococcus*, fecal *Enterococcus*, *Giardia lamblia*, *Cryptosporidium parvum*, and several viruses. Risk estimates for gastrointestinal illness and *Giardia* infection resulting from indirect and direct ingestion of contaminated water were calculated for three potential exposure scenarios: visitor, recreator, and homeless person. Single-event risk was first evaluated for the three individual exposure scenarios; overall risk was then determined over a 1-year period. Monte Carlo techniques were used to characterize uncertainty. Nearly all of the pathogen concentrations measured in the Passaic River exceeded health-based water quality criteria and in some cases were similar to levels reported for raw sewage. The probability of contracting gastrointestinal illness due to fecal *Streptococcus* and *Enterococcus* from incidental ingestion of water over the course of a year ranged from 0.14 to nearly 0.70 for the visitor and recreator scenarios, respectively. For the homeless person exposure scenario, the risk for gastrointestinal illness reached 0.88 for fecal *Streptococcus* and *Enterococcus*, while the probability of *Giardia* infection was 1.0. This risk analysis suggests that, due to the levels of pathogens present in the Lower Passaic River, contact with the water poses, and will continue to pose, significant human health risks until CSO discharges are adequately controlled or abated.

Microbial pathogens are ubiquitous in nature and are the second-leading cause of water body impairment in the United States (36). Once in a stream, lake, or estuary, they are capable of causing gastrointestinal, respiratory, skin, eye, ear, nose, and throat diseases in humans (28). Pathogen-related disease outbreaks following recreational contact with pathogen-contaminated surface waters have been well documented. For example, in 1982, an outbreak of gastrointestinal illness occurred among New York City police and firefighter scuba divers who swam in the Hudson and East rivers (32). In that instance, pathogens such as *Entamoeba histolytica* or *Giardia lamblia* were detected in the river water and in 60% of the affected divers. A 1998 review of 22 studies of recreational waters showed that the indicator organisms that correlate most closely with gastrointestinal illness are fecal *Enterococcus* and *Streptococcus* spp. for both marine water and freshwater and *Escherichia coli* for freshwater only (22).

In many settings, potentially pathogenic microbes reach surface water bodies via the release of untreated sewage through combined sewer overflows (CSOs) or sanitary sewer outfalls (SSOs). The presence of raw sanitary sewage in SSO releases is an unintended consequence that often results from a ruptured or clogged sanitary sewage pipe that has discharged its contents to the street surface and, thence, to nearby storm drains. SSO discharges typically contain between one million and one billion coliform bacteria per 100 ml of water and can also contain high levels of other pathogenic bacteria, viruses, or protozoans (36). In combined sewer systems (CSSs), storm water runoff and sanitary sewage are moved in the same system. During precipitation events, CSO releases intentionally bypass wastewater treatment plants and discharge directly to surface water bodies to avoid overloading the wastewater treatment plant. The combination of storm water and raw sewage dilutes the pathogen content of the effluent to some degree, but typical concentrations of total coliforms in CSO discharge waters have been reported to range between 100,000 and 10,000,000 in most probable number (MPN)/100 ml (20). To date, approximately 770 cities and communities containing about 40 million people are served by CSSs (29). CSSs are most commonly found in the midwestern and northeastern areas of the United States, where the sewer systems are generally older.

Viruses and protozoa are also found in CSO and SSO discharges. Viruses that have been measured in CSO or SSO discharges include poliovirus, infectious hepatitis virus, and coxsackie virus (36). *Giardia*, the cause of the most commonly reported protozoan infection from waterborne outbreaks in the United States (32), has been detected in treated wastewater at levels ranging from 0.0002 to 0.011 cysts per liter and in

* Corresponding author. Mailing address: ChemRisk, 25 Jessie Street, Suite 1800, San Francisco, CA 94105. Phone: (415) 618-3222. Fax: (415) 896-2444. E-mail: edonovan@chemrisk.com.

untreated wastewater at levels ranging from 2 to 200,000 cysts per liter (36). Similarly, *Cryptosporidium parvum* has been measured in treated wastewater at concentrations ranging from 0.0002 to 0.042 oocysts per liter, while untreated wastewater has reportedly contained between less than 0.3 and 13,700 oocysts per liter (36). In several recent studies, levels of *Giardia* and *Cryptosporidium* were measured in CSOs in urban areas during overflow events. *Giardia* concentrations ranged from 2 to 225 cysts per liter in one study that was conducted in the U.S. Environmental Protection Agency (USEPA) Region 2 area, which includes the states of New Jersey and New York (National Risk Management Research Laboratory, USEPA, poster presented at the EPA Science Forum 2003, Washington, DC), while another study conducted in Pittsburgh, PA, found levels ranging from 37.5 to 1,140 cysts per liter (27). *Cryptosporidium* was also detected in the Pittsburgh study.

Recent studies have suggested that recreators whose activities involve surface waters in highly urbanized areas with CSSs may be exposed to a significant pathogen-related risk (8, 9). For example, a survey in Baltimore Harbor (MD) found measurable levels of *Cryptosporidium* in hand wipe samples collected from anglers (25). In this study, 56 urban anglers were interviewed regarding fishing frequency, fish consumption, and species of fish caught and consumed, as well as demographic information. A total of 46 fish and hand wipe samples were collected; 10 of 18 (56%) hand samples and 7 of 28 (25%) fish samples were positive for *Cryptosporidium*. Significantly higher levels were measured on the hands, and it was theorized that this was due to the anglers handling multiple fish and to their "rinsing" their hands in the water.

In recent years, the USEPA has been active in addressing CSOs as potentially significant sources of pathogenic microorganisms. In 1994, USEPA published its CSO control policy, which was intended to establish a consistent national approach for controlling discharges from CSOs through its National Pollutant Discharge Elimination System (7). At that time, USEPA estimated that it would cost over $40 billion nationwide to control CSOs (37). More recently, USEPA prepared a report to Congress, in which it was noted that CSOs and SSOs can impact human health and the environment at the local watershed level (36). USEPA has initiated litigation against municipalities across the United States that are alleged to have inadequately controlled CSO or SSO sewage discharges into surface water bodies, demonstrating the increasing concern of USEPA about the risks posed by pathogens (35). Despite the significant costs associated with improving antiquated sewer systems, communities are expected to develop long-term CSO control plans with the objective of eventually attaining water quality standards in compliance with the Clean Water Act (33). For example, New York City, which has approximately 460 outfalls, plans to spend over $2 billion on a CSO abatement program which will include the planning, design, and construction of over 30 citywide projects designed to optimize the operation of the sewer collection system, pumping stations, and treatment plants during wet weather (19). Similar efforts of this scale have been conducted around the United States over the past 10 to 15 years (15, 38).

The objective of this analysis was to estimate pathogen-related disease risk for users of the Lower Passaic River in New Jersey. The Lower Passaic River is a 17-mile tidal stretch from the Dundee Dam to the river's mouth at Newark Bay and is part of the New York-New Jersey Harbor estuary. The drainage area is approximately 180 square miles, which includes portions of five counties (Essex, Hudson, Morris, Bergen, and Passaic counties) and 66 municipalities. The area surrounding the Lower Passaic River has been highly urbanized and industrialized since the mid-1800s. While there is a long history of pollution issues for this water body, there also have been efforts to improve water quality. Today, the Lower Passaic River Restoration Project is an integrated effort among EPA, the U.S. Army Corps of Engineers, the New Jersey Department of Transportation, the New Jersey Department of Environmental Protection (NJDEP), and natural resources trustees to perform, in cooperation with other stakeholders, including entities who may be responsible for historical or ongoing degradation, a comprehensive study leading to cooperative restoration of the river (21). As a part of this effort, USEPA recently prepared a draft risk assessment for the Lower Passaic River, which included recreator, visitor, and homeless person scenarios (2).

The Lower Passaic River contains 73 CSOs that discharge to the river at various times. These CSOs are capable of overflowing with as little as 1 inch of rainfall; over a 24- to 48-h period, this can potentially cause an estimated 125 million gallons of combined storm water and sanitary sewage to be discharged directly into the river (3). In addition to release events triggered by precipitation, some unintentional discharges may also occur during dry weather due to integrity failures of the CSO conduits. Currently, the lower section of the river is designated by the State of New Jersey for secondary-contact recreation, which includes activities such as fishing and boating (18). Angling and other recreational activities are relatively infrequent, due in part to the highly industrial and developed shoreline along the lower 6 miles of the river. However, recreational activities are known to occur as there are access points where individuals catch fish (which they may consume) and otherwise come in contact with surface water (14, 23, 24). In addition, homeless populations have been observed living along the shores of this section of the river (21).

This risk assessment characterizes and quantifies the human health risks associated with exposures to pathogens present in the Passaic River. In this analysis, representative concentrations of different pathogens in the river water were calculated from existing sampling data. Plausible exposure scenarios were developed in which direct and indirect contact with river water or CSO discharge was assumed to occur. Probabilities of gastrointestinal illnesses or infection were estimated based on established dose-response relationships for the various indicator bacteria and protozoa found to be present in the river.

MATERIALS AND METHODS

Available water sampling data for the Lower Passaic River were analyzed to (i) evaluate whether concentrations of pathogenic microorganisms exceeded applicable health-based standards and (ii), if so, estimate the potential health risks for several exposure scenarios based on designated and observed uses of the river. As summarized in Table 1 and described below, several sources of water quality data were evaluated for the Lower Passaic River. Of these, two data sets were considered appropriate for use in the risk calculations. Approximate sample locations for each data set are shown in Fig. 1.

IEC ambient water quality monitoring data. The Interstate Environmental Commission (IEC) conducted pathogen sampling in the Lower Passaic River at

TABLE 1. Summary of available water monitoring data for Lower Passaic River

Data source	Time period covered	Sampling location(s)	No. of samples collected	Type of microbes evaluated (unit)[a]	Mean	Maximum	Minimum	Note(s)
USGS[b]	1991 to 1997	USGS site 1389880 (Passaic River at Elmwood Park; less than 1 mile upstream of Dundee Dam)	31	Fecal coliform (colonies/100 ml)	2,725	92,000	<200	Data were also available for 1974 to 1981 but were not included in this analysis
				Enterococcus (colonies/100 ml)	380	9,000	5	
IEC	2003 (6 days between 11 August 2003 and 22 September 2003)	Six sampling locations around Newark Bay complex, including Passaic River	36	Fecal coliform (MPN/100 ml)	6,574	46,000	230	Samples collected during wet and dry conditions
				Total coliform (MPN/100 ml)	25,774	240,000	230	
				Fecal *Streptococcus* (MPN/100 ml)	2,988	24,000	4	
				Fecal *Enterococcus* (MPN/100 ml)	2,762	24,000	3	
Saybrook Place CSO	2003 (September 23)	Saybrook Place CSO (located within Passaic River Study Area). First sample collected from CSO itself, second from surface water within 10 ft of discharge point. Samples collected immediately after rainstorm	2	Total coliform (CFU/100 ml)		>30,000	>30,000	Results reported as TNTC
				Fecal coliform (CFU/100 ml)		>30,000	>30,000	Results reported as TNTC
				Fecal *Streptococcus* and fecal *Enterococcus* (CFU/100 ml)		>30,000	>30,000	Results reported as TNTC
				Escherichia coli		Positive	Positive	Laboratory results indicated that *E. coli* was clearly present, but it was not quantifiable because the other species were present in overwhelming numbers (5)
				Giardia (cysts/liter)		798	1,860	Based on two samples, one collected directly from discharging CSO (1,860 cysts/liter) and the other 10 ft downstream (798 cysts/liter)
PVSC[c]	2000 to 2001	Twelve stations sampled along Lower Passaic River (10 from bridges, two closest to Newark Bay from boat), two in Newark Bay (from boat), and two in Hackensack River (from boat)	574	Fecal coliform (bacteria/100 ml)	1,120	NA[d]	NA	Minimum and maximum values not presented in report

[a] The units CFU, MPN, colonies, and bacteria are used interchangeably.
[b] U.S. Geological Survey (USGS) data are reported as geometric means.
[c] PVSC, Passaic Valley Sewerage Commissioners.
[d] NA, not available.

six fixed locations on six different days between 11 August and 22 September 2003 (13). In total, 36 samples were analyzed for fecal coliform, total coliform, fecal *Streptococcus*, and fecal *Enterococcus* numbers. The sampling effort was consistent with USEPA's 1986 Ambient Water Quality Criteria for Bacteria guidelines, which recommend that geometric means should be calculated using at least five samples spaced over a 30-day period to characterize pathogen concentrations in surface waters (28). Two sets of the IEC samples (those collected on 3 September 2003 and 19 September 2003) were preceded by at least 48 h of completely dry conditions, whereas the other samples were collected within 48 h of rain.

Saybrook Place CSO. Two water samples were collected after a precipitation event on 23 September 2003 at the Saybrook Place CSO in Newark, NJ (6). The CSO pipe appeared to be approximately half-submerged, with roughly 3 ft of the pipe above the water surface (Fig. 2a). During the sample collection, light to moderate rain was falling. Discharge from the CSO pipe was clearly visible from

the street level (about 30 ft above the pipe). One sample was collected from the center of the CSO discharge. The second sample was collected from the surface water approximately 10 feet downstream of the CSO discharge point (Fig. 2b). Samples were collected using the hand-dip method (42) after it had been raining for several hours. Samples were analyzed for indicator bacteria (Table 1) as well as a number of viruses and protozoa (Table 2).

Statistical interpretation of microbial data. The data used in this analysis were obtained from multiple sources. As a result, concentrations of indicator bacteria were expressed using several different units (e.g., MPN, CFU, and bacterial counts) (12). For purposes of reporting, these terms have been used interchangeably as they all provide an estimate of the number of bacteria in a given sample. In this analysis, geometric mean values and arithmetic mean values were calculated from the raw data. Pathogen concentrations are frequently expressed as a geometric mean for the purposes of comparison with water quality standards or other health-based criteria, consistent with
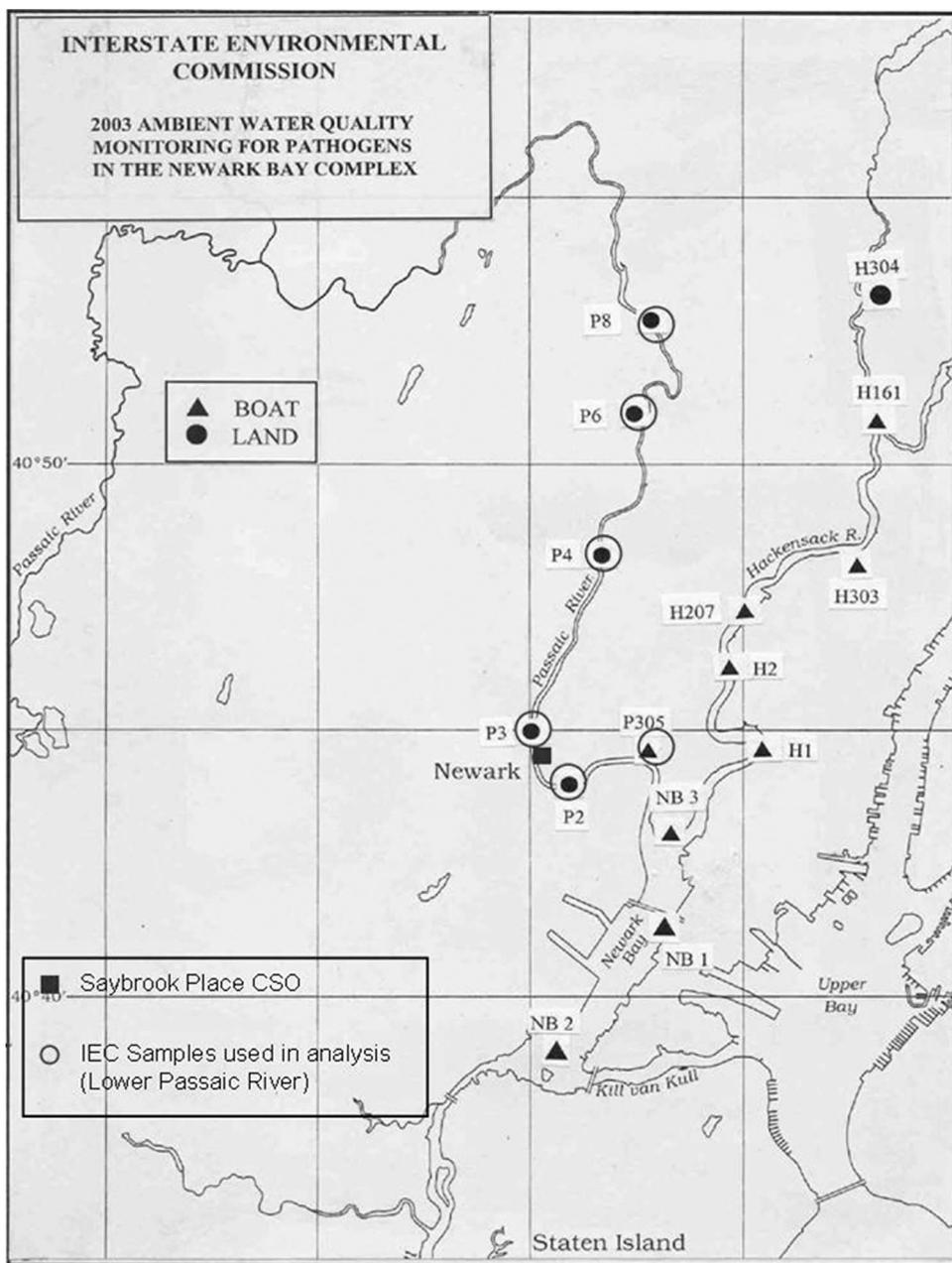
FIG. 1. Approximate sampling locations of water quality data considered in this analysis. Only boxed IEC data were used. Reprinted from reference 13 with permission of the publisher.

USEPA guidance (28). Geometric mean concentrations of fecal coliform and fecal *Enterococcus* bacteria were compared to New Jersey surface water quality standards (18) (Table 3). Arithmetic mean values were used in risk calculations (10).

Exposure scenarios. A human health risk assessment was conducted to evaluate the risks associated with pathogen exposure in the Lower Passaic River for the following scenarios: (i) recreator (e.g., swimmer), (ii) visitor (e.g., angler or picnicker), and (iii) homeless person. As noted previously, these scenarios are consistent with those used by USEPA in their draft risk assessment for the Lower Passaic River (2). For all pathogens, the exposure route was assumed to be ingestion. Default ingestion intake values were derived from the USEPA Risk Assessment Guidance of Superfund (RAGS), volume I, as well as the supplement to RAGS developed by USEPA Region 4 (39, 40). Additionally, scenario-appropriate assumptions were extrapolated from these defaults (Table 4). For each exposure scenario, risk was first calculated for a single exposure event;

overall risk was then determined over a 1-year period, based on the assumption that a recreator, visitor, or homeless person would have multiple exposure events over the year. Monte Carlo techniques were used to characterize the uncertainty associated with several assumptions used in the exposure scenarios, including ingestion rate and exposure frequency. Surface water data collected by the IEC were used in risk calculations for recreators and visitors based upon the assumption that the IEC data were more representative of ambient conditions throughout the lower section of the river. Data from the Saybrook Place CSO discharge were used in the risk calculations for the homeless person scenario, which is consistent with previous observations of homeless individuals living along the river and using CSO discharge to wash themselves or their possessions (3).

(i) Recreator. This scenario represents direct contact with surface water during activities such as swimming or water-skiing. Potential routes of pathogen exposure consist of direct and indirect ingestion of surface water. The use of a recreator scenario is consistent with USEPA's recent risk assessment of the
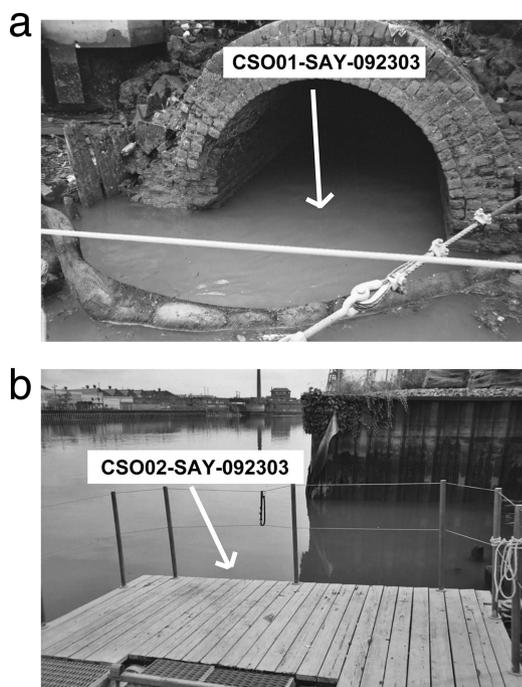
FIG. 2. (a) Saybrook Place CSO sampling location (CSO01-SAY-092303). (b) Saybrook Place CSO downstream sampling location (CSO02-SAY-092303).

Lower Passaic River (2). For the purposes of this assessment, it was assumed that the mean ingestion rate for a recreator was 36 ml per day (90th percentile range = 3 to 103 ml/day) during a visit to the river (considered to be an exposure "event"). This value was derived from USEPA guidance regarding the total amount of time spent outdoors at rivers and lakes (31), with the assumption that 20% of the total time at the river would be spent in the water (Table 4). Since this scenario is occurring in New Jersey, it is likely that recreational activities would occur during the warmer months around the summer. In addition, a triangular distribution was assumed for exposure frequency (days/year) for a recreator for the period of 1 year (minimum = 1, mode = 12, maximum = 95).

(ii) Visitor. The visitor scenario is intended to represent individuals who may engage in activities with minimal water contact, such as anglers, boaters, individuals wading in the surface water, and individuals engaging in other activities that may not be limited to the summer months. It is known that angling occurs at several points along the Lower Passaic River throughout the year (14, 23, 24), and USEPA considered this a complete pathway in their risk assessment of the Lower Passaic River (2). In this scenario, the potential route of exposure is indirect ingestion as a result of hand-to-mouth activities. Hand-to-mouth transfer may be significant for anglers who spend time eating or smoking while fishing. In this analysis, the mean incidental ingestion rate was assumed to be 7 ml/hour for adults and adolescents. This value was calculated using the same method described above for recreators (Table 4) and is similar to the 10-ml/hour value cited by USEPA risk assessment guidance for individuals exposed to surface water during wading (40). In addition, a triangular distribution was assumed for exposure frequency (days/year) for a visitor over a 1-year period (minimum = 1, mode = 2, maximum = 12), and it was assumed that these activities were not limited to summer months.

(iii) Homeless person. A number of homeless people live in temporary, make-shift shelters along the banks of the Lower Passaic River (3). In some cases, the actual discharge has reportedly been used for bathing or washing personal belongings. The homeless scenario was also included in USEPA's draft risk assessment as a complete exposure pathway (2). With high frequency of contact with CSO and surface water by homeless people living along the shoreline, it was assumed that incidental or even purposeful ingestion of surface water could be considerably higher than that experienced by recreators or visitors. In this assessment, the mean value for ingestion rate was 72 ml/hour; this value was based on the assumption that a homeless person could be in the water 40% of the total time spent at the river (Table 4). Because it is plausible that homeless individuals

would have ample opportunity for repeated exposure events along the river, a triangular distribution was assumed for exposure frequency over the 1-year period (minimum = 1, mode = 24, maximum = 150).

Dose-response relationship. (i) Fecal *Streptococcus*/*Enterococcus*. For this risk assessment, the health endpoint for indicator bacterial exposure is swimming-related gastrointestinal illness. The dose-response relationship is based on USEPA's 1986 standard, which reports a dose-response relationship of 104 fecal *Streptococcus*/*Enterococcus* organisms/100 ml causing 19 illnesses per 1,000 swimmers (28). This relationship was derived from studies involving swimmers in marine waters that were considered to be impacted by wastewaters. The dose-response relationship is described using the following mathematical equation: illness rate/1,000 people = 12.17 × $\log_{10}$(mean enterococcus density) + 0.20 (28).

The following equation was used to calculate the single-exposure illness rate. This equation also accounts for the implicit water ingestion rate in the above dose-response equation and the scenario-specific water ingestion rates.

$$\text{Risk}_{single} = (12.17/1,000) \times \log\left[C \times \left(\frac{\text{IR}_{water}}{\text{IR}_{swim}} \right) + 0.2 \right]$$

$$\text{Risk}_{annual} = 1 - (1 - \text{Risk}_{single})^{EF}$$

where risk_{annual} = annualized risk, risk_{single} = single-event risk, EF = exposure frequency (days/year), C = arithmetic mean concentration (CFU/ml), IR_{water} = incidental ingestion rate of water for scenario (ml/day), and IR_{swim} = incidental ingestion rate of water for dose-response regression (ml/day). The concentration term is based on the arithmetic mean such that the single-event risk properly characterizes cumulative risk (10).

(ii) *Giardia*. In addition, the impact of exposure to *Giardia* was considered. The health endpoint for *Giardia* is *Giardia* infection. Whether *Giardia* infection progresses to clinical illness (giardiasis) depends on a variety of host and proto-zoan factors. USEPA's water quality criteria document for *Giardia* (32) describes a human health risk assessment methodology using a dose-response model developed by Rose et al. (26): $P_{single} = 1 - \exp^{(-rN)}$ and $P_{annual} = 1 - (1 - P_{single})^{EF}$. The variables in this model are defined as follows: P_{single} = probability of infection for a single event, P_{annual} = annualized probability of infection, r = fraction of organisms ingested that initiate infection, and N = average number of ingested organisms.

The value of r developed by Rose et al. (26) was 0.01982 (95% upper confidence level, 0.009798 to 0.03582), an organism-specific constant. This dose-response model was based upon the experimental data of Rendtorff (1954), wherein doses of *Giardia* ranging from 1 to 1,000,000 cysts were ingested by human volunteers (26). The r value was also included in the Monte Carlo uncertainty analysis, which assumed an empirical distribution based on likelihood confidence intervals developed by Rose et al. (26).

TABLE 2. Additional microbes sampled for at Saybrook Place CSO

Pathogen	Value for sample (CFU/ml)[a]	
	Center of CSO (CSO01-SAY-092303)	River water 10 ft from CSO (CSO02-SAY-092303)
Citrobacter freundii	3,000	NF[b]
Gram-negative rods resembling *Enterobacter* species	NF	4,000
Gram-variable rods resembling *Myroides odoratus*	NF	3,000
Rathayibacter/Rothia species	NF	10,000
Aeromonas ichthiosmia	5,000	NF
Enterobacter cloacae	NF	2,000
Pantoea dispersa	4,000	NF
Kluyvera ascorbata	3,000	NF
Microbacterium lacticum	3,000	
Actinomycetes	8,000	10,000
Acinetobacter species	NF	3,000
Gram-variable rods	2,000	1,000
Gram-negative rods resembling *Pantoea* species	NF	2,000
Gram-positive rods	NF	3,000

[a] Unless otherwise noted, the bacterial information was provided by EMSL.
[b] NF, not found.

TABLE 3. Comparison of available monitoring data for Passaic River with New Jersey water quality standards[a]

| Pathogen | No. of organisms | | | | | |
| | New Jersey standard[b] | IEC (2003) | Exponent-Saybrook Place (2003) (n = 2 samples) | USGS | | PVSC (2000 to 2001) |
				1991 to 1997	1997 only	
Fecal coliform	GM = 770/100 ml for SE2 waters	GM = 2,980/100 ml	>30,000	2,725	606	1,120/100 ml[c]
	GM = 1,500/100 ml for SE3 waters	GM = 2,980/100 ml	>30,000	2,725	606	1,120/100 ml[c]
Fecal Streptococcus		GM = 930/100 ml	>30,000			
Enterococcus	GM = 35/100 ml for estuaries	GM = 800/100 ml	>30,000	380	200	
	Single-sample maximum = 104/100 ml for estuaries	>24,000/100 ml (maximum)	>30,000	9,000	400	

[a] Abbreviations: GM, geometric mean; USGS, U.S. Geological Survey; PVSC, Passaic Valley Sewerage Commissioners.
[b] Requires minimum of five samples spaced over a 30-day period.
[c] Arithmetic mean.

RESULTS

Saybrook Place CSO. As shown in Table 1, fecal coliform, fecal *Streptococcus*, and fecal *Enterococcus* bacteria were found to be present in the CSO discharge and river water samples at concentrations greater than 30,000 CFU/100 ml. Analytical laboratory sheets indicated that the samples had been analyzed by membrane filtration and that plate culture results were recorded as ">300 colonies" (5) or "too numerous to count" (TNTC). In addition, laboratory results clearly confirmed that *E. coli* was present in both Saybrook Place samples, although it was not possible to quantify them further than "TNTC" or determine whether the measured concentrations are similar to what has previously been reported for raw sewage.

Giardia cysts were also detected in the Saybrook Place CSO samples at concentrations of 1,860 cysts/liter (at the CSO) and 798 cysts/liter (10 feet downstream of the CSO). The value at the CSO was generally on the order of what has been reported for raw sewage (1,000 cysts/liter to 10,000 cysts/liter) and is greater than values typical of secondary treated wastewaters (10 cysts/liter to 100 cysts/liter) and surface waters (<10 cysts/liter) (32). It was noted in the analytical laboratory sheets that the matrix spike recovery values reported for the *Giardia* analyses were below 15%, suggesting that the results are biased low (1, 5). Acceptance criteria for the recovery using this method range from 13 to 111% for *Cryptosporidium* and from 14 to 100% for *Giardia*. Both sample methods indicate that there are some sample matrices which may prevent the acceptance criteria from being met (34; K. Connell, J. Scheller, K. Miller, and C. C. Rogers, presented at the American Water Works Association Water Quality Technology Conference, Salt Lake City, UT, 5 to 9 November 2000). Thus, it is possible that the low recovery percentages could be due to matrix interference resulting from the presence of iron or organic contaminants in the samples, which can impact the enrichment/purification step of the analysis.

Cryptosporidium was not detected in the samples. Again, it was noted in the analytical laboratory sheets that the recovery efficiency of one sample was below the 13% cutoff of the acceptable range, while the other was 16%. Given the low recovery efficiency, it is difficult to determine whether the in-

ability to detect *Cryptosporidium* means that it was not present in the water or is indicative of analytical interferences.

The Saybrook Place CSO samples were also analyzed for a variety of other indicator organisms or pathogens associated with gastrointestinal disease. Although not included in our risk assessment, male-specific and somatic coliphages (which can serve as indicators of fecal contamination in groundwater) were detected in both samples. Integrated cell culture/nested PCR analysis was used to evaluate the presence of human enteric viruses, including adenovirus, astrovirus, enteroviruses (coxsackie virus, echovirus, and poliovirus), reovirus, rotavirus, and hepatitis A virus. Based upon cytopathic effects observed in cell cultures and particle size, it appeared that the Saybrook Place sample taken directly from the CSO contained at least one infectious virus. Reovirus was also detected in this sample. Both samples were negative for adenovirus, astrovirus, enteroviruses, hepatitis A virus, and rotavirus. Additional bacterial analyses indicated the presence of *Citrobacter freundii* in the CSO sample, as well as a number of gram-negative rod species and other bacteria in samples collected downstream from the CSO (Table 2) (6).

IEC ambient water quality monitoring data. The IEC data showed that bacterial levels increased by more than 10-fold when rain had fallen in the prior 48 h, which suggests that wet-weather events resulted in discharge of indicator bacteria into the Passaic River (Fig. 3). This is consistent with the Saybrook Place CSO samples, which were collected immediately following a rainstorm and showed significantly elevated pathogen levels. An evaluation of the National Climatic Data Center's 24-hour rainfall data prior to collection of the IEC samples indicates that the bacterial levels were still elevated well after rainfall ended (16, 17). Overall, the levels of fecal coliform and *Enterococcus* bacteria were above the NJDEP's standards (18) and the USEPA's criteria (28) in all but one sample, indicating that water quality standards and criteria were exceeded even when rain had not fallen in the prior 24 or 48 h.

Risk characterization. (i) Bacteria. Using mean exposure levels of 2,988 MPN/100 ml and 2,762 MPN/100 ml from the IEC data for exposure to fecal *Streptococcus* and fecal *Entero-*

TABLE 4. Assumptions used in risk calculations

Parameter	Symbol	Unit	Distribution	Note(s)
Concn				
Fecal *Streptococcus*				
IEC	Cs	MPN/100 ml	Normal (mean = 2,988, SD = 785)	Distribution of mean determined using central limit theorem because $n > 30$
Saybrook		CFU/100 ml		Distribution of mean could not be determined because $n = 2$
Enterococcus				
IEC	Ce	MPN/100 ml	Normal (mean = 2,762, SD = 784)	Distribution of mean determined using central limit theorem because $n > 30$
Saybrook		CFU/100 ml		Distribution of mean could not be determined because $n = 2$
Giardia				
Saybrook, CSO	Cg	Cysts/ml		Distribution of mean could not be determined because $n = 1$
Saybrook, downstream of CSO				Distribution of mean could not be determined because $n = 1$
Giardia	rg	No unit	Empirical (2.5th = 0.009798; 12.5th = 0.01336; 25th = 0.01584; 50th = 0.0198; 75th = 0.02466; 87.5th = 0.02845; 97.5th = 0.03582)	Rose et al. (26); calculated based on likelihood confidence intervals
Water ingestion	IR$_{hourly}$	ml/h		
Recreator				50 ml/h; incidental ingestion rate during swimming
Visitor				10 ml/h; adults/adolescents—surface water during wading
Homeless person				50 ml/h; incidental ingestion rate during swimming
Time spent outdoors at river	T	Minutes/day	Empirical (5th = 20; 25th = 60; 50th = 150; 75th = 320; 90th = 511; 95th = 615)	USEPA, 1997, Table 15-110 (31)
Fraction of time at river spent in water	F	%		
Recreator				Assumed 20%
Visitor				Assumed 20%
Homeless person				Assumed 40%
Incidental water ingestion rate implicit in AWQC[a] dose-response relationship, swimming	IR$_{AWQC}$	ml/day	Triangular (minimum = 10; mode = 16; maximum = 100)	Ingestion rate used to account for uncertainty in incidental ingestion of water inherent in AWQC dose-response equation for incidental ingestion of water during swimming (Dufour et al., 2006 [4])
Incidental water ingestion rate	IR$_{daily}$	ml/day		IR$_{daily}$ = IR$_{hourly}$ × F × (T/60)
Recreator			Calculated	
Visitor			Calculated	
Homeless person			Calculated	
Exposure frequency	EF	Days/yr	Triangular	Maximum no. of days limited by meteorological factors such as
Recreator			Minimum = 1, mode = 12, maximum = 95	
Visitor			Minimum = 1, mode = 2, maximum = 12	precipitation and temp
Homeless person			Minimum = 1, mode = 24, maximum = 150	

[a] AWQC, ambient water quality criteria.

coccus, respectively, annualized risks of contracting gastrointestinal illness via incidental ingestion were 0.68 and 0.67, respectively, for the recreator scenario. The probability of illness for the visitor scenario was 0.14 for both types of bacteria.

Likewise, when the Saybrook Place CSO data were used to calculate risk estimates for the homeless person scenario, the resulting risk was 0.88 for both *Enterococcus* and fecal *Streptococcus* (Table 5).
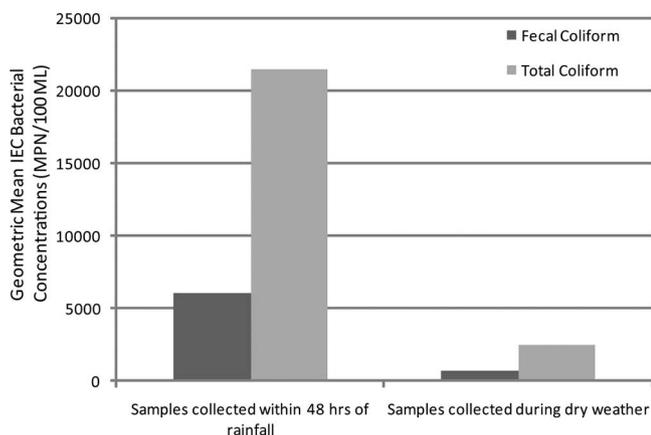
FIG. 3. Geometric means of reported concentrations of fecal coliforms and total coliforms in the Passaic River (IEC sampling 2003).

(ii) Giardia. The homeless person scenario was the only appropriate scenario for the use of the Saybrook Place CSO protozoan data given that homeless individuals have been observed having direct contact with CSO discharge. *Giardia* was the only identified protozoan, and of the two samples, the sample collected directly from the CSO was used in the risk calculations. These calculations were based on the assumption that a homeless person would likely be using water much closer to the shore and, in some cases, directly from the CSO. By application of the model of Rose et al. (26) to an annualized exposure scenario, the resulting risk estimate ($P = 1.00$) suggests that every homeless person who is exposed would be infected with *Giardia*, although it is important to note that the progression from infection to illness depends on a variety of host factors. Based on the uncertainty analysis, the use of the CSO discharge data versus the sample collected downstream did not have a significant impact on the overall risk estimate.

Quantitative uncertainty analysis. (i) Recreators and visitors. As mentioned previously, the IEC data were used to characterize risk for recreators and visitors. The results were very similar for fecal *Streptococcus* and *Enterococcus* for both scenarios. The exposure frequency parameter was the primary contributor to total uncertainty for risk. For both fecal *Streptococcus* and *Enterococcus*, exposure frequency contributed approximately 93% of the total uncertainty for recreators and approximately 86% for visitors. Again for both strains of bacteria, the time spent in the water (hours/day) while at the river contributed from 5.6 to 5.8% (recreators) to 10.7 to 11% (visitors) of the uncertainty, the ingestion rate uncertainty ranged from 0.8% (recreators) to 2.3% (visitors), and the uncertainty associated with the concentration of bacteria contributed less than 1% of the total uncertainty of the risk estimates.

(ii) Homeless individuals. For the homeless person scenario, data from the CSO were used to characterize risk of gastrointestinal illness due to exposure to fecal *Streptococcus*/*Enterococcus* and the risk of infection with *Giardia*. There was no difference between fecal *Streptococcus* and *Enterococcus* with respect to the relative contribution of each parameter to the total uncertainty of the risk estimate. For the bacteria, the exposure frequency contributed 96.7% of the total uncertainty, followed by time spent in the water (2.7%) and the scenario-

specific ingestion rate (0.6%). For *Giardia* risk, the assumption regarding the amount of time spent in the water had the greatest contribution to the overall risk estimate (71.3%), followed by exposure frequency (23.4%) and the uncertainty associated with the value r used in the dose-response equation (5.3%).

DISCUSSION

As with any risk assessment, there were several potential sources of uncertainty in this analysis. First, the basic assumption in the exposure assessment, that human contact occurred shortly after a rainstorm, is conservative. The levels of exposure to pathogens following a CSO discharge would be expected to decline with the passage of time. This, in turn, could result in lower risks of pathogen-related disease if contact occurred during a prolonged dry period. However, it is important to note that IEC data collected during dry days suggest that pathogen levels remain elevated in the Lower Passaic River even when CSOs are not actively discharging.

Second, a number of the pathogens detected in the Saybrook Place CSO samples are normally present in soils, plants, or animals. While it is important to consider all possible sources of pathogens when evaluating pathogen risk at a single CSO, it has been well documented that CSOs can release large amount of pathogenic microorganisms into water bodies. The impact on water quality of CSO discharges during wet weather was apparent from this analysis. Samples collected at or near the Saybrook Place CSO demonstrated that levels of enteric bacteria were several orders of magnitude greater than water quality standards. Concentrations over 30,000 CFU/100 ml greatly exceed the New Jersey water quality criteria of 1,500 counts/100 ml for fecal coliforms and 35 counts/100 ml for *Enteroccus* in estuaries. In addition, these values were several orders of magnitude greater than the single-sample maximum for *Enterococcus* of 104 counts/100 ml set forth in the New Jersey standards. It was also clear that a number of pathogenic microorganisms capable of causing serious disease, including *Giardia* and *Citrobacter freundii*, are being discharged into the Lower Passaic River during precipitation events through CSOs.

Sampling data from 10 feet downstream of the CSO also indicated high pathogen concentrations in the immediate vicinity following a CSO discharge. Because CSO outfalls are not always visible (e.g., they may be hidden behind bushes or

TABLE 5. Annualized risk estimates for bacteria and protozoa

Organism	Mean risk estimate (90% prediction interval)		
	Recreator[a]	Visitor[a]	Homeless person[b]
Bacteria			
Fecal *Streptococcus*	0.68 (0.26–0.96)	0.14 (0.05–0.28)	0.88 (0.54–1.0)
Enterococcus	0.67 (0.26–0.96)	0.14 (0.05–0.27)	0.88 (0.54–1.0)
Protozoa			
Giardia[a]	ND[c]	ND	1.00

[a] Based on water sampling data collected by IEC ($n = 36$); considered to be representative of typical conditions along the Lower Passaic River.
[b] Based on water sample collected from discharging CSO ($n = 1$). This value was used only for the homeless person scenario based on observations of homeless individuals in direct contact with outfall discharge.
[c] ND, no data.

rocks), it is plausible that recreators or visitors could be exposed to the high levels observed in this study due to contact with water along the shore near an outfall following a CSO discharge (e.g., while fishing or wading along the shoreline). In these situations, the use of IEC data, which were not specifically collected near CSOs, could result in an underestimation of risk.

While this risk assessment characterized the health risks associated with several indicator bacteria and *Giardia*, sampling at the Saybrook Place CSO indicated that other potentially pathogenic microorganisms were present in the discharged water. The level of risk for contracting specific illnesses, though unquantified, may be considerable, because several species are opportunistic pathogens that affect especially the young, the old, and those with compromised immune systems. The presence of *Citrobacter freundii* is significant, because it can cause meningitis with high morbidity and mortality potentials. It is also important to note that, despite some of the high risk estimates in this assessment (e.g., 100% probability of infection for homeless people exposed to *Giardia*), the development of illness depends upon a variety of factors specific to an individual's immunity, such as age, preexisting illness, or other host-specific factors. These host-specific factors may also determine if the illness will progress from a subclinical or asymptomatic state and, in some cases, whether it will be acute or chronic in nature (11).

The Lower Passaic River has a long history of impaired water quality. While the water quality of the Lower Passaic River is considerably better today than it was 100 years ago, there are still a number of impediments to attaining the status of a fully functional ecological and recreational resource. Effective restoration of the Lower Passaic River, as envisioned by the Lower Passaic River Restoration Project, will need to reduce human health risks significantly, which will require that all sources of such impacts be addressed (21). Nearly all available data show that pathogen levels are elevated above health-based criteria during both dry and rainy conditions. Thus, risks associated with pathogen exposures must be considered in addition to those posed by chemicals in the water and sediment. Health risks associated with pathogens are based upon a single, acute exposure, which can present a more difficult environmental management challenge than theoretical risks due to long-term exposure, such as might occur with environmental contaminants. One of the overall objectives of the Clean Water Act is to achieve a "fishable/swimmable" condition (41), and the Lower Passaic River is designated by NJDEP for secondary contact recreation and "any other reasonable uses" (18). Based upon this analysis, the currently existing health risks associated with pathogen exposures are incompatible with these objectives under both dry weather conditions (indicated by IEC survey data) and wet weather conditions (indicated by Saybrook Place CSO and IEC sampling data).

The health risks posed by discharges from CSOs have been recognized by USEPA (36). Since the mid-1990s, the agency has indicated that reducing the reliance by communities on CSOs is a priority; accordingly, USEPA has developed a number of programs to respond to the problem. The increase in enforcement actions on the part of USEPA and state governments against municipalities in recent years underscores the importance of addressing CSOs. However, it also indicates that municipalities may still be contributing to the degradation of nearby water bodies by their continued reliance on antiquated systems, particularly those that rely heavily on combined sewerage systems with CSOs.

From a risk assessment perspective, it is clear that the release of pathogens into the Lower Passaic River via CSOs remains an impediment to achieving a consistent level of water quality that will allow for recreational use of the river as envisioned by the State of New Jersey (21, 30). Clearly, major urban systems can reduce, and many have reduced, their reliance on systems with CSOs. Addressing CSOs impacting the Passaic River to reduce the risk of gastrointestinal illness to current users is critical to the improvement of the water quality in accordance with the objectives of the Clean Water Act.

REFERENCES

1. **Analytical Services, Inc.** 2003. Analytical reports for samples CSO01-SAY-092303 and CSO02-SAY-092303. Analytical Services, Inc., Williston, VT.
2. **Battelle.** 2007. Lower Passaic River Restoration Project. Draft focused feasibility risk assessment. Appendix C. Contract no. KC-ACE2002-18. Battelle, Columbus, OH.
3. **Battelle.** 2005. Lower Passaic River Restoration Project. Pathway analysis report. Contract no. DACW41-02-D-003. Battelle, Columbus, OH.
4. **Dufour, A. P., O. Evans, T. D. Behymer, and R. Cantu.** 2006. Water ingestion during swimming activities in a pool: a pilot study. J. Water Health **4:**425–430.
5. **EMSL Analytical.** 2003. Analytical reports for samples CS001-SAY-092303 and CS002-SAY-092303. EMSL reference no. 370304632. EMSL Analytical, Westmont, NJ.
6. **Exponent.** 2004. Pathogen sampling and preliminary human health risk assessment—Saybrook Place combined sewer overflow, Newark, NJ. Exponent, Chicago, IL.
7. **Federal Register.** 1994. Combined sewer overflow (CSO) control policy; notice. Fed. Regist. **59:**18688–18698.
8. **Graczyk, T. K., B. M. Evans, C. J. Shiff, H. J. Karreman, and J. A. Patz.** 2000. Environmental and geographical factors contributing to watershed contamination with Cryptosporidium parvum oocysts. Environ. Res. **82:**263–271.
9. **Graczyk, T. K., R. Fayer, J. M. Trout, M. C. Jenkins, J. Higgins, E. J. Lewis, and C. A. Farley.** 2000. Susceptibility of the Chesapeake Bay to environmental contamination with Cryptosporidium parvum. Environ. Res. **82:**106–112.
10. **Haas, C. N.** 1996. How to average microbial densities to characterize risk. Water Res. **30:**1036–1038.
11. **Haas, C. N., J. B. Rose, and C. P. Gerba.** 1999. Quantitative microbial risk assessment. John Wiley & Sons, Inc., New York, NY.
12. **Ingraham, J. L., and C. A. Ingraham.** 1995. Introduction to microbiology. Wadsworth Publishing Company, Belmont, CA.
13. **Interstate Environmental Commission.** 2003. 2003 annual report. Interstate Environmental Commission, New York, NY. http://www.iec-nynjct.org /reports/2004/annualreport_03.pdf.
14. **Kinnell, J. C., M. F. Bingham, E. A. Hastings, R. Ray, V. Craven, and M. Freeman.** 2007. A survey methodology for collecting fish consumption data in urban and industrial water bodies (part 1). J. Toxicol. Environ. Health A **70:**477–495.
15. **Milwaukee Metropolitan Sewerage District.** 2007. Deep Tunnel history/facts. Milwaukee Metropolitan Sewerage District, Milwaukee, WI. http: //www.mmsd.com/wastewatertreatment/deep_tunnel_history_facts.cfm.
16. **National Climatic Data Center.** 2003. Unedited local climatological data. Hourly precipitation table. Newark Liberty International Airport (EWR). September 2003. National Climatic Data Center, Asheville, NC.
17. **National Climatic Data Center.** 2003. Unedited local climatological data. Hourly precipitation table. Newark Liberty International Airport (EWR). August 2003. National Climatic Data Center, Asheville, NC.
18. **New Jersey Department of Environmental Protection.** 2005. Surface water quality standards. N.J.A.C. 7:9B. New Jersey Department of Environmental Protection, Trenton, NJ.
19. **New York State Department of Environmental Conservation.** 2004. State enforcement targets quality of water near New York City. New York State Department of Environmental Conservation, Albany, NY. http://www.dec.ny .gov/environmentdec/18679.html.
20. **Novotny, V., K. R. Imhoff, M. Olthof, and P. A. Krenkel.** 1989. Karl Imhoff's handbook of urban drainage and wastewater disposal. John Wiley & Sons, New York, NY.

21. **ourpassaic.org.** 2007. The Lower Passaic River Restoration Project fact sheet. http://www.ourpassaic.org/projectsites/premis_public/DM/index.cfm/fact.pdf?fuseaction=GetDoc&DocId=5026.

22. **Pruss, A.** 1998. Review of epidemiological studies on health effects from exposure to recreational water. Int. J. Epidemiol. **27:**1–9.

23. **Ray, R., V. Craven, M. Bingham, J. Kinnell, E. Hastings, and B. Finley.** 2007. Human health exposure factor estimates based upon a creel/angler survey of the lower Passaic River (part 3). J. Toxicol. Environ. Health A **70:**512–528.

24. **Ray, R., V. Craven, J. Kinnell, M. Bingham, M. Freeman, and B. Finley.** 2007. A statistical method for analyzing data collected by a creel/angler survey (part 2). J. Toxicol. Environ. Health A **70:**496–511.

25. **Roberts, J. D., E. E. Silbergeld, and T. K. Graczyk.** 2007. A probabilistic risk assessment of Cryptosporidium exposure among Baltimore urban anglers. J. Toxicol. Environ. Health A **70:**1568–1576.

26. **Rose, J. B., C. N. Haas, and S. Regli.** 1991. Risk assessment and control of giardiasis. Am. J. Public Health **80:**1440–1446.

27. **States, S., et al.** 1997. Protozoa in river water: sources, occurrence, and treatment. J. Am. Water Works Assoc. **89:**74–87.

28. **U.S. Environmental Protection Agency.** 1986. Ambient water quality criteria for bacteria. 1986 EPA 440-5-84-002. U.S. Environmental Protection Agency, Washington, DC.

29. **U.S. Environmental Protection Agency.** 2005. Combined sewer overflow demographics. U.S. Environmental Protection Agency, Washington, DC. http://cfpub.epa.gov/npdes/cso/demo.cfm?program_id=5.

30. **U.S. Environmental Protection Agency.** 2005. Compliance and enforcement—Clean Water Act. U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/compliance/resources/cases/civil/cwa.

31. **U.S. Environmental Protection Agency.** 1997. Exposure factors handbook (EFH), vol. I, II and III. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

32. **U.S. Environmental Protection Agency.** 1998. *Giardia*: human health criteria. Document EPA 823-R-002. U.S. Environmental Protection Agency, Washington, DC.

33. **U.S. Environmental Protection Agency.** 2001. Guidance: coordinating CSO long-term planning with water quality standards reviews. EPA-833-R-01-002. U.S. Environmental Protection Agency, Washington, DC.

34. **U.S. Environmental Protection Agency.** 2001. Method 1623: *Cryptosporidium* and *Giardia* in water by filtration/IMS/FA. EPA-821-R-01-025. U.S. Environmental Protection Agency, Washington, DC.

35. **U.S. Environmental Protection Agency.** 2005. Cases and settlements. Office of Compliance and Enforcement, U.S. Environmental Protection Agency, Washington, DC. http://cfpub.epa.gov/compliance/cases/.

36. **U.S. Environmental Protection Agency.** 2004. Report to Congress. Impacts and control of CSOs and SSOs. EPA 833-R-04-001. U.S. Environmental Protection Agency, Washington, DC.

37. **U.S. Environmental Protection Agency.** 2001. Report to Congress. Implementation and enforcement of the combined sewer overflow control policy. EPA 833-R-01-003. U.S. Environmental Protection Agency, Washington, DC.

38. **U.S. Environmental Protection Agency.** 2001. Report to Congress. Implementation and enforcement of the combined sewer overflow control policy. Appendix C: CSO community case studies. EPA 833-R-01-003. U.S. Environmental Protection Agency, Washington, DC.

39. **U.S. Environmental Protection Agency.** 1989. Risk assessment guidance for Superfund, vol. I. Human health evaluation manual (part A). EPA/540/1-89/002. U.S. Environmental Protection Agency, Washington, DC.

40. **U.S. Environmental Protection Agency.** 2000. Supplemental guidance to RAGS: region 4 bulletins, human health risk assessment bulletins. U.S. Environmental Protection Agency Region 4, Atlanta, GA.

41. **U.S. Environmental Protection Agency.** 2004. Water quality standards: designating waterbodies. U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/watertrain/cwa/cwa8.htm.

42. **U.S. Geological Survey.** 2000. Microbial monitoring for the U.S. Geological Survey National Water Quality Assessment Program Water Resources Investigations. Report 00-4018. U.S. Geological Survey, Reston, VA.