Association of
Metropolitan
Sewerage Agencies

To: *Interested Stakeholders*

From: *AMSA*

Date: *May 10, 2004*

Subject: *CHARACTERIZATION OF THE POTENTIAL ADVERSE HUMAN HEALTH EFFECTS ASSOCIATED WITH COMBINED SEWER OVERFLOWS AND SANITARY SEWER OVERFLOWS – LIMITATIONS OF AMSA TECHNICAL MEMORANDUM*

The Association of Metropolitan Sewerage Agencies (AMSA) is making available to its members and other interested parties this technical memorandum entitled "Characterization of the Potential Adverse Human Health Effects Associated with Combined Sewer Overflows and Sanitary Sewer Overflows" prepared for AMSA by EOA, Inc. The memorandum details the results of an investigation conducted by EOA to collect available technical data and information and, to the extent feasible, assess the potential human health effects associated with combined and sanitary sewer overflows.

It is important to note that this memorandum is only a preliminary examination of potential human health effects of combined and sanitary sewer overflows (CSOs and SSOs). Since the available data on viable pathogens in overflows and actual exposure to overflow events are limited, the results of the evaluation are limited in their application. It is AMSA's intent to pursue additional projects either through its Technical Action Fund or in cooperation with the Water Environment Research Foundation to answer some of the questions raised by the memorandum, increase the amount of available data on the presence, viability and infectivity of pathogens in CSOs and SSOs, and conduct site-specific exposure analyses to evaluate actual human health risk.

AMSA is releasing this memorandum now, before any additional work is done, in an effort to increase the level of understanding regarding the potential health effects of CSOs and SSOs. Members of the research community have expressed an interest in seeing the results and AMSA feels strongly that it is important to bring to bear as much information as possible on the subject. At this point, AMSA has not initiated any additional projects but is actively considering an effort to examine exposure scenarios in several case study communities.

Memorandum Scope and Limitations

In June 2003, AMSA's Pathogens Workgroup retained the services of EOA, Inc. to conduct a preliminary characterization of potential human health effects associated with CSOs and SSOs. The characterization was based on available pathogen data and the technical memorandum

prepared by EOA examined the probability of infection or illness associated with a hypothetical exposure to an SSO or CSO event. For the purposes of this characterization, it was assumed – and this key assumption carries with it distinct limitations – that an individual was actually exposed to some varying amount of SSO or CSO. The probability of that individual becoming infected or ill from a particular pathogen as a result of that ingested quantity of CSO or SSO was then evaluated. ***The risk characterization is incomplete as it does not evaluate the probability of someone actually being exposed to that particular quantity of CSO or SSO or that the pathogens present in the CSO or SSO are actually capable of causing infections.*** EOA's review found that much of the data needed for such a comprehensive risk assessment is simply not being collected currently. EOA concluded that given the site-specific nature of exposure, the only appropriate way to assess risk associated with overflows is to examine the potential exposure and risk associated with an individual overflow event.

Other limitations of the characterization, as discussed in Section 5.1.2 of the memorandum, include the fact that the viability and/or infectivity of the organisms and the laboratory recovery efficiency in enumerating the levels of organisms were not accounted for in most cases for the available data. These limitations, especially the lack of data and the need to examine exposure on a case-by-case basis, are the major drivers for the potential follow-up projects AMSA is considering pursuing.

If you would like additional information on the technical memorandum, please contact Chris Hornback, AMSA's Director of Regulatory Affairs at 202/833-9106 or *chornback@amsa-cleanwater.org*.

Association of Metropolitan Sewerage Agencies

Characterization of the Potential Adverse Human Health Effects Associated with Combined Sewer Overflows and Sanitary Sewer Overflows

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TECHNICAL MEMORANDUM

Association of Metropolitan Sewerage Agencies

Characterization of the Potential Adverse Human Health Effects Associated with Combined Sewer Overflows and Sanitary Sewer Overflows

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1.0 INTRODUCTION

1.1 Objectives

The principal objective of this investigation was to assimilate available technical data and information to assist in characterizing, to the extent feasible, the potential adverse human health effects that may be associated with human exposure to pathogenic microorganisms in sanitary sewer overflows (SSOs) and combined sewer overflows (CSOs).

The characterization of potential adverse human health effects was carried out via numerical simulation. Factors considered include representative ranges for (1) concentrations of pathogens in untreated and primary treated wastewater, (2) dilution of wastewater during CSO and SSO events, (3) volume of wastewater the public may be exposed to during CSO and SSO events, (4) pathogen infectivity, and (5) number of individuals exposed. The results of the investigation provide insight regarding how the data may be used to prioritize the level of public health concern associated with CSO and SSO events.

This investigation included three key tasks. An overview of those tasks is presented below.

- ***Literature Review***: Gather data on concentration of representative pathogens of public health concern in raw wastewater.
- ***Exposure Data Collection:*** Identify dilution characteristics of CSO/SSO events, estimate the volume of CSO/SSO water that the public may be exposed to, and discuss how the relative number of individuals that are likely to be exposed during CSO and/or SSO events is linked to risk management.
- ***Risk Characterization:*** Develop a series of tables and/or graphs that are representative of the risks to public health associated with overflow events.

1.2 Motivation for Investigation

In the Consolidated Appropriations Act for fiscal year 2001 (2000 Amendments to the Clean Water Act), Congress made several changes to the Clean Water Act (CWA) regarding CSOs. Among those changes was a requirement for the U.S. Environmental Protection Agency (U.S. EPA) to provide two reports to Congress. The first report, entitled "Implementation and Enforcement of the Combined Sewer Overflow Control Policy" was delivered on January 29, 2002 (U.S. EPA 2003c). The second report, which is due to Congress on December 15, 2003 is to investigate (1) the extent of the human health and environmental impacts caused by municipal CSOs and SSOs, (2) the resources spent by municipalities to address these impacts, and (3) an evaluation of the technologies used by municipalities to address these impacts.

In embarking upon the task of assessing the human health impact portion of Congress' request, EPA's initial research indicated that little data were available that linked waterborne illness or other exposures to CSOs and SSOs (U.S. EPA 2002). To assist in understanding the factors that complicate the collection of information and data to characterize the potential adverse human health effects associated with exposure to pathogens via CSOs and SSOs, EPA held an expert workshop in August 2002 on the public health impacts of sewer overflows (U.S. EPA 2002).

There was general agreement at the EPA workshop on several aspects of the possible health risks associated with SSOs and CSOs, including the specific pathogens of concern, the illnesses that are associated with those pathogens, which pathogens produce the most serious illnesses, the myriad of exposure pathways, and the sensitive subpopulations of most concern. There was not, however, agreement on the relative importance of CSOs and SSOs in comparison to public health risk from exposure to other sources of microbial pathogens. Nevertheless, the report states that completely eliminating CSOs and SSOs would have a real public health benefit.

Given the potential human health and financial implications of new regulations related to CSOs and SSOs, AMSA retained the services of EOA, Inc. to design and carry out this preliminary investigation to characterize, to the extent feasible based on readily available data, the potential adverse human health effects associated with human exposure to pathogenic microorganisms in CSOs and SSOs.

1.3 Background

Combined sewer systems (CSSs) are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies. These overflows are called CSOs and contain not only stormwater but also untreated human and industrial waste, toxic materials, and debris (U.S. EPA 2003b). CSOs are considered point source discharges, and as such, are subject to National Pollutant Discharge Elimination System requirements. However, CSO's are not subject to secondary treatment requirements, which are applicable to publicly owned treatment works (POTWs) under the Clean Water Act (U.S. EPA 2003b).

Properly designed, operated, and maintained sanitary sewer systems (SSSs) are meant to collect and transport all of the sewage that flows into them to a POTW. However, occasional unintentional discharges of raw sewage from municipal sanitary sewers occur in almost every system. These types of discharges are called SSOs and can cause the release of untreated sewage from manholes, into home basements, or onto streets, playgrounds, or surface waters. SSOs may be caused by blockages or breaks in sewer lines from excessive rainfall or snowmelt infiltration through the ground and into leaky sanitary sewers, inflow through roof drains connected to sewers, broken pipes, poorly connected sewer service lines, or undersized sewer and pump systems (U.S. EPA 2003a).

Both CSOs and SSOs are comprised partially or primarily of raw wastewater. Therefore it should be clear that both CSOs and SSOs may contain microbial pathogens known to cause a variety of adverse human health impacts. However, the degree to which CSOs and SSOs contribute to waterborne illness has not to date been well characterized. The need to assess potential public health impacts associated with SSO's and CSO's was specified in the 2000 Amendments to the CWA.

When considering the infectious disease implications of human exposure to wastewater, the following factors need to be considered: (1) for waterborne illness or disease to occur an agent of disease (pathogen) must be present, (2) the agent must be present in sufficient concentration to produce disease (dose), and (3) a susceptible host must come into contact with the dose in a manner that results in infection or disease (Cooper 1991b).

An exposure pathway may be defined as the course taken by a microorganism from its source to reach its receptor (human). Individuals may be exposed to raw sewage released from a POTW in an SSO or CSO event through ingestion of wastewater via a number of different pathways. For example, in an SSO event one potential route of exposure is for wastewater (and thus pathogens) to be accidentally in contact with an individual's hands and subsequently ingested after being transferred to the mouth through direct contact or contact with food. By contrast, individuals may be exposed to pathogens from a CSO event while swimming or recreating in a surface water that received the overflow water.

One important aspect of this investigation was to conduct a preliminary characterization of the human exposure to pathogens in SSOs and CSOs and the potential public health risk. Based on research conducted over the last twenty years, it is reasonable to infer that the primary risk from recreational exposure to waterborne pathogens is associated with gastroenteritis from viral contamination (Cabelli et al. 1982; Fankhauser et al. 1998; Levine and Stephenson 1990; Mead et al. 1999; Palmateer et al. 1991; Pruss 1998; World Health Organization 1999). Human contact with water in fecally contaminated receiving waters may also cause other adverse health outcomes such as acute febrile respiratory illness (Fleisher et al. 1996), general respiratory illness, ear infections (Fleisher et al. 1996), eye ailments, skin rashes (Ferley et al. 1989), and other less common health outcomes. Although the cumulative risk faced by recreators is a function of all of the pathogens present in the receiving water and the potential subsequent health outcomes, this investigation in a manner consistent with federal regulatory guidelines and recently published state-of-the-art risk assessment studies (Soller et al. 2003a), focuses on the risk of gastroenteritis.

For this investigation, the number of pathogens that an individual may be exposed to (dose) during or because of a CSO or SSO event, is defined as the volume of water ingested multiplied by the pathogen concentration (Cooper 1991b). Differences in human exposure levels between CSO and SSO events are not well documented in the epidemiologic literature. Therefore professional judgment has been employed to estimate the relative volumes of water that individuals may be exposed to during CSO and SSO events.

2.0 APPROACH

2.1 Pathogens of Public Health Concern in Raw Wastewater

2.1.1 Pathogens in Raw Wastewater

Waterborne infectious agents of intestinal origin are discharged in human and animal feces, and the presence of microbial pathogens in wastewater has been a concern for decades. Four groups broadly classify these organisms: viruses, bacteria, protozoa, and helminths. A brief description of the characteristics of the various categories of microbial pathogens is provided below (EOA Inc. 2001; Soller et al. 2003b).

Viral Pathogens. Viruses are obligate intracellular parasites; that is, they have no cell structure of their own. Viruses are therefore are incapable of replication outside a host organism. They range in size from approximately 0.025 to 0.350 μm and thus can only be observed with an electron microscope. There are over 140 types of known human enteric viruses. Enteric viruses replicate in the human intestinal track and are shed in fecal material of infected individuals. The term "enteric viruses" is applied to any viruses disseminated by the fecal route. These viruses are further divided into several groups based on morphological, physical, chemical and antigenic differences. The most commonly studied group in water is the enteroviruses which includes for example, poliovirus, coxsackie and echovirus.

Bacterial Pathogens.
Fecal material contains many types of harmless bacteria that colonize the human intestinal tract and can contain up to 10^{12} bacteria per gram. One group of intestinal bacteria, the coliform bacteria, has historically been used as an indicator organism to address environmental pollution by wastewater and wastewater treatment plant performance. Other important bacteria may be present in human feces that are both pathogenic to humans and transmittable by the waterborne route.

Protozoan Parasites. Most protozoan parasites produce cysts/oocysts (i.e., resting stage) that can survive outside their host under adverse environmental conditions. In general, protozoan parasitic cysts are larger than bacteria. They range in size from 2 to 15μm. Both symptomatic and non-symptomatic individuals excrete protozoan cysts/oocysts. Protozoan parasites are similar in nature to viruses in that they do not reproduce outside the host organism (i.e., in the environment).

Helminthic Parasites. Helminths of pathogenic importance include the roundworm and the hookworm. The ova constitute the infective stage of parasitic helminths and they are particularly resistant to environmental factors. Helminthic eggs and cysts tend to range in size from 5 to 150 μm and may be spherical or cylindrical. Helminthic infections tend to be transmitted through contact with contaminated soil and food. Many helminthic infections require an intermediate animal host. Successful control of helminthic infections can be directly correlated with eradication of the intermediate host, health education, provision of toilets and the proper treatment and disposal of wastewater sludge. For the most part, helminths are not a major health problem in the United States.

Symptoms associated with waterborne microbial infections range from mild to serious and are briefly summarized below (Feachem et al. 1983; Mead et al. 1999). It should however be understood that not all infected individuals exhibit symptoms of disease. That is, infected individuals can be either infected but not symptomatic (carrier state) or infected and symptomatic (diseased). The percent of infections that result in disease (symptoms) varies from pathogen to pathogen. A literature review on this subject has been recently published (Soller et al. 2003b). A detailed discussion on this subject is beyond the scope of this investigation, however the difference between infection and disease (or equivalently illness) should be appreciated.

Viruses potentially found in raw wastewater include Adenoviruses, Rotavirus, Enteroviruses, Calicivirus, Astrovirus, Norwalk virus and Norwalk-like viruses, Hepatitis A, and Poliovirus. Waterborne viral infections can lead to a wide range of adverse health effects. These symptoms include, but are not limited to gastroenteritis, vomiting, diarrhea, meningitis, sore throat, or flu-like symptoms, depending on the specific pathogen. Hepatitis A infections can cause jaundice, fatigue, and fever, in addition to some symptoms caused by infections of other viral pathogens.

Bacterial pathogens known to be present in raw wastewater include: *Campylobacter*, *Enterococcus spp.*, *E. coli 0157:H7* and other pathogenic *E. coli, Vibrio cholerae*, *Pseudomonas aeruginosa*, *Salmonella spp.*, *Salmonella Typhi*, *Shigella*, and *Yersinia spp.* *Salmonella spp.* are associated with salmonellosis, which characterized by fever, abdominal cramping, and diarrhea. Occasionally, those infected by *Salmonella* develop Reiter's syndrome, which can cause joint pain, eye irritation, and painful urination. In addition, Reiter's syndrome can lead to chronic arthritis. Infections of *Shigella* lead to bacterial dysentery or shigellosis, which is often characterized by bloody diarrhea, a fever, and stomach cramping.

Protozoa such as *Cryptosporidium parvum*, *Cyclospora cayetanensis*, *Entamoeba histolytica*, *Giardia lamblia*, *Balantidium coli*, and *Toxoplasma gondii* may be found in raw wastewater. *Cryptosporidium* causes gastroenteritis characterized by diarrhea, loose or watery stools, stomach cramps, upset stomach, and a low grade fever. Children and pregnant women are more susceptible to dehydration from *Cryptosporidium*, and the disease may in fact be life threatening to those with weakened immune systems. *Giardia lamblia* causes diarrhea, loose or watery stools, stomach cramps, and upset stomach. Additionally, *Giardia* infections may lead to weight loss and dehydration, particularly in children and pregnant women. *Giardia* is highly contagious, and generally lasts 2-3 weeks. Infections by other protozoa may lead to a wide range of ailments including flu-like symptoms, ulcers, abdominal pain, headache, fever, nausea, seizures, and amoebic meningoencephalitis.

2.1.2 Pathogens of Public Health Concern

Conducting an assessment of the public health risk associated with exposure to pathogens requires the selection of a representative pathogen or pathogens on which to conduct the assessment. Although a wide range of pathogens have been identified in raw wastewater, relatively few pathogens are believed to be responsible for the majority of the waterborne illnesses caused by pathogens of wastewater origin (Mead et al. 1999). The pathogens that have

been reported to be responsible for the vast majority of illnesses in the United States ("pathogens of public health concern") from all sources are the focus of this investigation.

To identify the pathogens of public health concern, research conducted by the Centers for Disease Control (CDC) was employed (Mead et al. 1999). In characterizing food-related illness and death in the United States, Mead and co-workers estimated the annual total number of illnesses caused by known pathogens (adjusting for the fact that many illnesses are not reported) in the United States. A summary of those estimates is presented in Table 1. Inspection of Table 1 indicates an estimated 38.6 million cases of illness occur annually in the United States, with 5.2 million cases from bacterial pathogens, 2.5 million from parasitic pathogens, and 30.9 million from viral pathogens.

Table 1 Annual Total Disease Burden From Known Pathogens in the U.S.
(Source: Mead et al., 1999)

	Estimated Tota # Cases	% Foodborne Transmission
BACTERIA		
Salmonella nontyphoidal	1,412,498	95
Shigella spp.	448,240	20
Campylobacter spp.	2,453,926	80
Others	890,270	
Bacteria Subtotal	5,204,934	
PROTOZOA		
Cryptosporidium parvum	300,000	10
Giardia	2,000,000	10
Toxoplasma gondii	225,000	50
Others	16,316	
Protozoa Subtotal	2,541,316	
VIRUSES		
Norwalk	23,000,000	40
Rotavirus	3,900,000	1
Astrovirus	3,900,000	1
Others	83,391	
Virus Subtotal	30,883,391	
TOTAL	38,629,641	

Further inspection of Table 1 indicates that approximately 85% to 90% of all non-foodborne infections in the United States are thought to be caused by viral pathogens (i.e., enteric viruses). The relative importance of viral pathogens in waterborne transmission of disease, is supported by data from the World Health Organization (World Health Organization 1999) and research conducted over the last 20 years on exposure to waterborne pathogens through recreational activities (Cabelli 1983; Fankhauser et al. 1998; Levine and Stephenson 1990; Palmateer et al. 1991; Sobsey et al. 1995). Norwalk-like viruses have been reported to account for 23,000,000 illnesses each year, of which 60% are estimated to be non-foodborne. Rotavirus accounts for 3,900,000 illnesses each year, of which 99% are non-foodborne (Mead et al. 1999).

Rearding protozoa, *Giardia lamblia* has been reported to cause 2 million illness cases per year, of which 90% are non-foodborne, and *Cryptosporidium parvum* causes 300,000 illnesses each year, of which 90% are non-foodborne (Mead et al. 1999). Many of the important bacterial illnesses in the United States demonstrate a high level of foodborne transmission. Of those bacterial pathogens which account for the non-foodborne illnesses in the United States, *Salmonella* (*Salmonella spp.* and non-typhoidal), *Shigella, and Campylobacter spp.* together have been reported to account for approximately 4.3 million of the 5.2 million annual bacterial illness cases in the U.S (of which, approximately 95%, 20%, and 80% respectively, are foodborne, respectively) (Mead et al. 1999).

For the purposes of this investigation, the primary criteria used to select pathogens as being representative of SSO and CSO events include: (1) the likely presence of the pathogen in CSO/SSO events based on known presence in wastewater, and (2) the estimated importance of the pathogen relative to the total disease burden in the United States and likely importance relative to the number of cases of waterborne disease in the United States. From the list of pathogens identified by EPA (EPA 833-R-02-002) and known to be present in wastewater, and CDC's estimated disease burden in the United States, the pathogens of public health concern selected for this investigation are: Norwalk-like viruses and rotavirus (Human Viruses), C*ryptosporidium parvum and Giardia lamblia* (Protozoa), and *Salmonella spp. and Shigella spp.* (Bacteria).

Given the reported data that the above selected pathogens of public health concern are responsible for a large majority of waterborne infections in the United States, it is assumed for this investigation that the potential public health risk associated with exposure to these pathogens provide a conservative representation of the overall human health risk through contact with SSO and/or CSO events.

2.2 Methodology

2.2.1 Microbial Risk Assessment Methodology

Microbial risk assessment involves evaluating the likelihood that an adverse health effect may result from human exposure to one or more pathogens. A review of the recent work conducted in the field of microbial risk assessment indicates that two fundamental approaches for microbial risk assessment are pervasive in the literature (Soller et al. 2003b). In general, those approaches may be categorized as static, individual–based risk assessment, or dynamic, population-based risk assessments.

The static model (NRC 1983) is commonly used as a generic framework for carrying out microbial risk assessments related to water- and food-borne pathogens (Crabtree et al. 1997; Farber et al. 1996; Sanaa et al. 2000; Voysey and Brown 2000). Assessments using a static model for evaluating microbial risk typically focus on estimating the probability of infection or disease to an individual as a result of a single exposure event. These assessments generally assume that multiple or recurring exposures constitute independent events with identical distributions of contamination (Regli et al. 1991). Secondary transmission (e.g., person-to-person transmission) and immunity are assumed to be negligible or that they effectively cancel each other out. In actuality, secondary transmission would increase the level of infection/disease in a

community relative to a specific exposure to pathogens, and immunity would decrease the level of infection/disease in a community relative to a specific exposure to pathogens (Soller et al. 2003b).

In the static model, it is assumed that the population may be categorized into two epidemiological states: a susceptible state and an infected or diseased state. Susceptible individuals are exposed to the pathogen of interest and move into the infected/diseased state with a probability that is governed by the dose of pathogen to which they are exposed and the infectivity of the pathogen. A schematic diagram of the static model is presented in Figure 1 (Colford et al. 2003).

The epidemiological states represented in this static model are Susceptible and Infected/Diseased. Although pathogens may derive from a number of potential environmental sources, in this investigation, it is assumed that susceptible individuals are exposed to pathogens from CSO and SSO events. The probability that a susceptible individual becomes infected or diseased is a function of the dose of pathogens to which that individual is exposed and the infectivity of the pathogen.

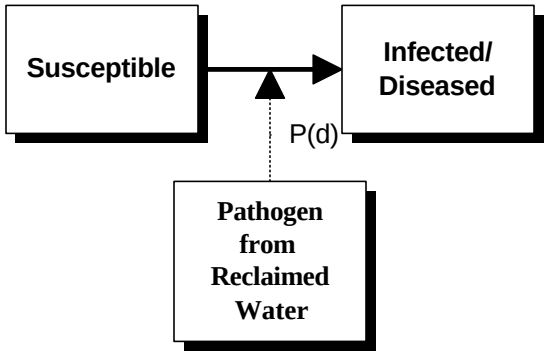

Figure 1 Static Risk Assessment Conceptual Model

Another methodology that has been employed as a risk assessment model is a dynamic model (Eisenberg et al. 1996; Eisenberg et al. 1998; EOA Inc. 1995; EOA Inc. and U.C. Berkeley 1995; EOA Inc. and U.C. Berkeley 1999; Soller et al. 2003a). In a dynamic risk assessment model, the population is assumed to be broken into a group of epidemiological states. Individuals move from state to state based on the natural history of the specific infectious disease (duration of infection, duration of immunity, etc.). Only a portion of the population is in a susceptible state at any point in time, and only those in the susceptible state can become infected or diseased through exposure to microorganisms. In a dynamic model, the probability that a susceptible person moves into an exposed state is governed by the dose of the pathogen to which they are exposed, the infectivity of that pathogen, and the number of infected/diseased individuals with whom they may come into contact (Anderson and May 1991; Hethcote 1976). Because the infectious disease process in a population is fundamentally a dynamic process, the most rigorous and scientifically defensible approach for modeling the infectious disease process mathematically is to employ a dynamic model (Soller et al. 2003b). Given limited information on the total number of diseased individuals, host immunity, and other requisite information by which to compare

conditions under which static and dynamic models would predict similar or divergent estimations of risk (e.g., person to person disease transmission risk), a static risk assessment approach has been employed for this investigation. This use of the static model in a screening level risk characterization, is consistent with recent literature in the field describing conditions in which the use of the static model is appropriate (Soller et al. 2003b).

The static microbial risk assessment model was implemented in this investigation through a series of numerical simulations. In each simulation, the value for each variable in the model (concentration of pathogen, volume ingested, dilution, etc.) was selected randomly from a feasible range (specified during the literature review), and a probability of infection was computed. This process (known as Monte Carlo simulation) was repeated thousands of times for each numerical simulation.

2.2.2 Characterization of Exposure

For waterborne disease transmission to occur, a disease causing agent (pathogen) must be present in sufficient concentration to produce infection (dose) and a susceptible host must come into contact with the pathogen in a manner that can result in infection and consequent disease (Cooper 1991b). Consistent with previous work in the field, for this investigation, the dose or index of exposure is computed by multiplying the concentration of the particular microbiologic agent in water with the assumed volume of water ingested.

Both SSO's and CSO's contain raw wastewater. SSOs may be associated with wet weather events in which raw wastewater is diluted with rainwater or groundwater, or may occur during dry weather (for example due to a broken pipe)[1]. There is however, a lack of reliable data from which to draw dilution values in SSOs. Thus, as a health protective assumption, it is assumed for this investigation that human exposure to pathogens via an SSO event occurs with undiluted raw wastewater. In an SSO event, it was assumed that the exposures associated with likely activities (e.g. incidental contact) could be characterized with volumes ranging from 0.1 to 100 ml. Volumes employed in the analysis included 0.1 ml, 1 ml, 10 ml and 100 ml. (Note that the upper portion of the range was employed to bracket the potential risk, even though this level of exposure seems unlikely).

CSO's were assumed to contain both a wastewater component and a component of dilution water (stormwater and/or receiving water). Thus, dilution in a CSO was modeled stochastically to achieve a range of pathogen doses ingested. First, it was assumed that stormwater dilutes wastewater within an outfall during a CSO event. This dilution ranged from 2:1 to 10:1 (personal correspondence and best professional judgment). Various dilutions were assumed to also occur outside of the CSS outfall. These dilutions ranged from zero additional dilution to 100:1 (based on personal correspondences and best professional judgment). Although it is likely that stormwater contains pathogenic microorganisms, sufficient data were not found in the literature to quantitatively characterize those concentrations of our list of pathogens of concern (e.g., only

[1] The potential ranges of dilutions that occur under wet and dry weather SSOs may vary substantially. For the purposes of this assessment, the exposure conditions presented for SSOs, represent best estimates of dry weather SSOs. The exposures and subsequent risks associated with wet weather SSOs are most likely more similar to those presented in the CSO sections than in the SSO sections.

indicator data are available). Therefore, the analysis presented herein, represents the risk attributable to the overflow event. Note that the total risk to human health associated with exposure to receiving waters containing an overflow event may be higher than that described herein, depending on the levels of pathogens present in the stormwater and receiving water.

In a CSO event, it was assumed that the volume of water ingested ranged from 1 ml (e.g. incidental contact) to 100 ml (e.g. recreation in a receiving water during a CSO event) (U.S. EPA 1989). Volumes employed in the analysis included 1 ml, 10 ml, 50 ml and 100 ml. Reductions in pathogen levels due to die-off were not included in the analyses, although die-off may be an important factor if for example a CSO occurs during a warm weather period in which recreation occurs in the receiving water during days subsequent to a CSO event.

2.2.3 Pathogen Infectivity

Infectivity for the viral, protozoan, and bacterial pathogens of public health concern were computed by employing the published dose-response relations for each of the respective pathogens. The probability of infection due to exposure to *Cryptosporidium parvum* and *Giardia lamblia* was assumed to follow an exponential dose-response relation. The exponential dose-response relation is a one parameter model that assumes that the distribution of organisms between doses is random, that each organism has an independent and identical survival probability, and that the minimum number of organisms required to initiate infection is one (Haas et al., 1996).

The probability of infection due to rotavirus, *Salmonella spp.*, and *Shigella spp* was assumed to follow a beta-poisson dose-response relation (Regli et al. 1991). The beta-poisson dose-response relation is a two parameter model that allows for a distribution of microorganism-host interaction probabilities (Haas et al. 1999).

Given the relative disease burden due to Norwalk-like viruses (Table 1), and that 1) a Norwalk virus dose-response relation has not yet been published (Lindesmith et al. 2003), and 2) quantitative occurrence data for Norwalk-like viruses in wastewater do not yet exist in the published literature, it was necessary to develop a method to estimate the overall risk of infection from human enteric viruses attributable to an overflow (CSO or SSO) event. To facilitate this estimate, in each numerical simulation the risk of infection from rotavirus exposure was first computed. To estimate the total risk of infection from viral pathogens attributable to the overflow event, the probability of infection from rotavirus exposure was then scaled by the proportion of all estimated of non-foodborne viral infections that are rotavirus infections in the U.S. annually (0.18). This was assumed to be a reasonable approach to account for Norwalk-like virus infectivity in the assessment. The resulting probability of illness was then bounded by 1.0.

3.0 LITERATURE REVIEW

The scientific and technical literature was reviewed to identify (1) representative concentrations of the pathogens of public health concern in raw and primary treated wastewater, CSOs, and SSOs, (2) the volume of water likely to be ingested during CSO/SSO events, (3) the dilution of wastewater that occurs during CSO/SSO events, and (4) representative concentrations of the pathogens of public health concern in stormwater.

The review focused on peer reviewed literature from the early 1980s through 2003 and was carried out using on-line literature services including Current Contents, Medline, PubMed, Melvyl (University of California), Biosis, and ISI's Web of Science. Based on this review, approximately 500 citation titles and abstracts were reviewed. Approximately 150 of those articles were thought to be pertinent to the investigation and were obtained and reviewed.

The literature review indicated that limited data were available to characterize pathogen concentrations in stormwater (other than indicator organisms), the volume of water likely to be ingested during CSO or SSO events, the dilution of wastewater that occurs during CSO/SSO events, and representative concentrations of pathogens of public health concern in CSOs and SSOs.

3.1 Concentration of Pathogens of Public Health Concern in Raw Wastewater

3.1.1 Viral, Protozoan, and Bacterial Pathogens of Public Health Concern

Concentration ranges of viral, parasitic, and bacterial pathogens of public health concern identified in the literature review are summarized in Tables 2, 3, and 4, respectively. The literature review made it apparent that there are methodologic differences in the way that pathogens are analyzed, and the corresponding units in which they are reported. Equivalence issues in sample enumeration methods were found. For example, bacteria concentrations were reported in some studies in units of CFU (colony forming units), while others reported in MPN (most probable number). Similarly, virus concentrations were reported in various units of measure (most common were focus forming units: FF or FFU; or plaque forming units: PFU). The reported values were standardized to the extent possible, to facilitate comparison.

In addition to the pathogens of public health concern identified in Section 2.1, several other important waterborne pathogens may be found in raw wastewater and therefore may also be present in CSOs and/or SSOs. For example, several viral pathogens, such as Cocksackie virus, and Poliovirus, are often present in raw wastewater, the concentrations of which were found during the literature review. For completeness, the results of the literature for those pathogens are also presented in Table 2. However, this additional information was not used further in the analysis presented in Section 4.0.

Table 2 Concentrations of Viral Pathogens in Raw Wastewater

	Raw Wastewater			Primary Effluent		
Pathogen	Range	Source	Notes	Range	Source	Notes
Rotavirus	5.4 X 10^3 ffu/L	Bosch et al. (1998)	Spain	5-30 FF/l	Bosch et al. (1988)	Spain
	100- 2.5 X 10^2/L	Toranzos et al. (1988)	Bolivia			
	10-2.2 X10^3/L	Toranzos et al. (1988)	Colombia			
	9X10^4/L	Oragui et al. (1989)	Brazil			
	23-6.5 X 10^2/L	Mehnert and Stewien (1993)	Brazil			
	10-175 ffu/L;	Smith and Gerba (1982)	USA	7.5-3.7X10^2/L	Smith and Gerba (1982)	
	36-510 ffu/L	Rao et al. (1987)	USA			
	1-321 FF/L	Hejkal et al. (1984)	USA			
Enterovirus	39-708 PFU/l	Bosch et al. (1986)		2-12 PFU/L	Bosch et al. (1988)	
	1.7-20/L	Lipp et al. (2001)				
	10^5 PFU/L	Wyn-Jones and Sellwood (2001)				
	10 PFU/L	Rose et al.(1996)	arithmetic mean			
	7.5 - 8X10^2 PFU/L	Hejkal et al. (1984)				
	10 PFU/L	York and Burg (1998)				
	1.5 X 10^3 mpniu/L	Payment et al. (2001)	range 4-12516	10^3 mpniu/L	Payment et al. (2001)	Range 1-10^4 mpniu/L
	3X10^4/L	EPA (1992); Cooper and Olivieri (1995)				
	10^3-10^5/L	Feachem et al. (1983)				
	10^5-10^6/L	Stewart (1990)		10^3- 5 X 10^4/L	Stewart (1990)	
Coxsackievirus	36- 1.7 X10^2 CPU/L	Kirkelis et al. (1985)		10^8 Viral Units/L	Clarke et al. (1961)	
Poliovirus	182-4.9 X10^5 /L	Irving (1982)		10^8 Viral Units/L	Clarke et al. (1961)	
Norwalk-Like Calicivirus	10^7 particles/L	Lodder et al. (1999)	RT-PCR results			
Total Culturable Viruses	10^3-10^5/L	Feachem et al. (1983)		1.7X10^3- 5X10^5/L	Stewart (1990)	
				9 X10^2 - 6X10^3 PFU/L	Yanko (1993)	median values

Table 3 Concentrations of Parasitic Pathogens in Raw Wastewater

	Raw Wastewater			Primary Effluent		
Pathogen	Range	Source	Notes	Range	Source	Notes
Cryptosporidium	.004-25 oocysts/L	Cooper et al., (1997)				
	13-73 oocysts/L	Grimason et al. (1993)	Kenya			
	13-52 oocysts/L	Rose (1986)				
	15 oocysts/L	Rose et al. (1996)	arithmetic mean			
	4.7 $X10^3$ oocysts/L	Chauret et al. (1999)				
	15 oocysts/L	York and Burg (1998)				
	<0.06 - 260 oocysts/L	Gennaccaro et al. (2003)	mean =70			
	0.3-1.2 X 10^2 oocsyts/L	Rose and Carnahan (1992)				
	26 oocysts/L	Payment et al. (2001)		10 oocysts/L	Payment et al. (2001)	primary/secondary
	10^2- 7$X10^2$ oocysts/L	CSDLAC (2003)	EPA Method 1623			
	1 - 4$X10^3$ oocysts/L	Yates (1998)		1- 3.9 $X10^3$/L	Yates (1998)	
Giardia lamblia	.004-3.2 X 10^3 cysts/L	Cooper et al., (1997)				
	69 cysts/L	Rose et al. (1996)				
	125-10^5 cysts/L	Rose & Carnahan (1992); Fox & Fitzgerald (1979)				
	212-6.2 $X10^3$cysts/L	Grimason et al. (1993)	Kenya			
	1.1 $X10^4$ -4.5 $X10^4$ cysts/L	CSDLAC (2003)	EPA Method 1623			
	9$X10^3$-2$X10^5$ cysts/L	Stewart (1990)		7 $X10^3$-1.2$X10^4$ cysts/L	CSDLAC (2003)	
	10^5 cysts/L	Yates (1998)		7 $X10^4$-1.5$X10^5$ cysts/L	Yates (1998)	
	8.25 $X10^3$ cysts/L	Chauret et al. (1999)				
	1.5 X 10^3 cysts/L	Payment et al. (2001)		6.4 X 10^3 cysts/L	Chauret et al. (1999)	primary effluent
	2.5 X 10^4 cysts/L	Garcia et al. (1999)		3.5 X 10^2 cysts/L	Payment et al. (2001)	primary/secondary
	9.6 X 10^3- 2.4 X 10^5 cysts/L	Kowal et al. (1982)		1.7 X 10^3 cysts/L	Garcia et al. (1999)	
Entamoeba histolytica	4 cysts/L	Foster and Englebrecht (1973)				

Table 4 Concentrations of Bacterial Pathogens in Raw Wastewater

	Raw Wastewater			Primary Effluent		
Pathogen	Range	Source	Notes	Range	Source	Notes
Campylobacter jejuni	3.7 X10^3 MPN/100 mL	Holler (1988)				
Salmonella spp.	2.2-9.2 MPN/100mL	Coper et al., (1997)	Salmonella spp.			
	0.3-1.3x10^4	Cooper et al. (1992)	Mean 1/100mL			
	2.3-8X10^3 MPN/100mL	Feachem et al. (1983)				
	8X10^3 MPN/100mL	NRC (1996)	Salmonella spp.	8 X 10^2/100mL	NRC (1996)	Salmonella spp.,w/ chlorination
	500-8X10^3 MPN/100mL	NRC (1998)		1.1 X 10^8 -7.5 X 10^8 MPN/100mL	Jimenez et al. (2001)	Salmonella spp.,w/ chlorination
	2-4.6X10^2 MPN/100mL	Gore et al. (1999)	interceptor and sewage combined	1.6 X 10^3-3.4X10^4/100mL	Stewart (1990)	Salmonella spp.; Primary plus disinfection
Shigella dysenteriae	1-10^3/100mL	Feachem et al. (1983)				
	6.3 X 10^5 CFU/100mL	Hench et al. (2003)	g. mean	1.26 X 10^4 CFU/100mL	Hench et al. (2003)	
	10^3 MPN/100mL	NRC (1996)		10^2 MPN/100mL	NRC (1996)	
	Not dectected (<1/L)	Cooper et al. (1992)	biweekly samples, 9 mos.			
Vibrio	10-10^4 MPN/100mL	Kott and Betzer (1972)				

The literature review revealed several other protozoan pathogens, such as *Entamoeba histolytica* and *Balantidium coli* may be found in raw wastewater, and thus sewer overflows. For completeness, the results of the literature review for those pathogens are also presented in Table 3. In addition to *Salmonella* and *Shigella*, concentration ranges were identified for several other bacterial pathogens. For example, *E. Coli 0157:H7* is known to be responsible for many foodborne disease outbreaks in the U.S, and *E. Coli ETEC* has been identified in raw wastewater. These values are also reported in Table 4 for completeness.

The literature review also included a search for concentrations of pathogens in primary treated wastewater. Pathogen reduction across primary treatment varied from minimal reduction (Payment et al. 2001) to approximately an order of magnitude reduction (Stewart 1990).

Based on the literature review, representative concentrations of the pathogens of public health concern for this investigation were developed (Table 5). The representative ranges were developed by inspecting the ranges summarized in Tables 2 through 4, and excluding values that seemed to be anomalously high or low, based on the rest of the results for each of the pathogens of interest. These ranges were employed in the numerical simulations that are described in Section 4.

Also shown in Table 5 are the type of dose response function for each of the pathogens of public health concern and the corresponding dose response values for each pathogen[2].

Table 5 Pathogen Concentrations Used for Numerical Simulations

Pathogen Type	Pathogen	Concentration Range Used in Simulation	Dose Response Function [2]	Dose Response Parameter	Reference for Dose Response Parameter
Bacteria	Salmonella	20-80,000 MPN/L[1]	Beta Poisson (Disease)	23,600[a]; 0.3126[b]	Haas et al., 1999
					Dupont et al, 1969
	Shigella	<10-6,300,000 MPN/L[1]	Beta Poisson (Disease)	1,120[a]; 0.21[b]	Shaughnessy et al, 1946 Levine 1972
Protozoa	Giardia	125-200,000 Cysts/L	exponential (Infection)	50,23	Rose et al., 1991
	Cryptosporidium	1-700 Oocysts/L	exponential (Infection	238	Dupont et al., 1995 Haas, et al., 1996
Viruses	Rotavirus [3]	1-510 FFU/L	Beta Poisson (Infection)	6.17[a];0.2531[b]	Ward et al., 1986 Regli et al., 1991

1Table 1 values for Salmonella and Shigella are shown in MPN per 100 ml

2 Dose response data were fit to either infection or disease data as shown in paranthesis

3 Note only data from US were used in simulations, although international data are also reported in Table 2

[a] Median infectious dose: N50

[b]

[2] As a point of reference, a review of the literature indicated that the concentration of Giardia cysts in relatively pristine waters ranged from 0.1 to 5.2 cysts/L and appeared to be present throughout all seasons (Ongerth, J.E., 1989)

3.1.2 Limitations of Available Data for Shigella

Review of Tables 4 and 5 indicate that the reported concentrations of *Shigella* in raw wastewater include an extremely wide range varying from <10 to greater than 10^6 organisms per liter (Cooper et al. 1992; Hench et al. 2003). Preliminary risk characterizations were initially developed using this range. However it was apparent from the preliminary work that the uncertainty in the concentration of *Shigella* in raw wastewater prevented its use in the simulations or any sort of reasonable interpretation of the results. Further, it is very difficult to culture and enumerate *Shigella spp.* from raw wastewater because of the presence of large numbers of interfering bacteria.

The risk estimates from the preliminary characterizations that were based on the upper portion of the reported range (Hench et al. 2003) did not seem to be consistent with the available empirical evidence on the endemic levels of *Shigella* infection in the United States (Mead et al. 1999). Further, sewage treatment plant workers do not appear to have an elevated incidence of *Shigella* infections (Cooper 1991a), supporting the previously stated concerns regarding the uncertainty in the concentration of *Shigella* in raw wastewater. The results based on the lower end of the reported range are more in line with the estimated number of annual illnesses reported by CDC. Therefore, given the limited data available to characterize the concentration in raw wastewater and the uncertainty associated with those data, the quantitative characterization of the risk associated with *Shigella* infection has not been included herein. Based on the preliminary analysis, it is unlikely that this omission would substantially affect the overall findings of this investigation, however addressing this data gap would be a reasonable focus of future research.

3.2 Data Collection for Exposure

Based on the results of the literature review, it is apparent that the degree of human exposure that occurs during SSO and CSO events are not well documented. In addition to the concentration of pathogens in raw wastewater, the pieces of data that are needed to characterize human exposure to pathogens from a CSO and/or SSO event include the volume of water ingested, the dilution of wastewater with stormwater (for a CSO or a wet weather SSO), and the dilution of wastewater with receiving waters (for a CSO). In addition, if one were to investigate the total risk to an individual from exposure to an overflow event, at a minimum, the concentration of pathogens in stormwater and the receiving water would need to be known.

Since data characterizing the volume of water ingested, the dilution of wastewater with stormwater (for a CSO), and the dilution of wastewater with receiving water (for a CSO) were not available, best professional judgment was employed based on available guidance from U.S. EPA and several conversations with municipal agency staff. A summary of the exposure-related variables employed in the numerical simulations is presented in Table 6.

Table 6 Summary of Exposure Variables Used In Numerical Simulation

Type of Event	Model Parameter	Simulation Values	Distribution
SSO	Volume Ingested	0.1 ml; 1 ml; 10 ml; 100 ml	-
CSO	Volume Ingested	1ml; 10 ml; 50 ml, 100 ml	-
	Dilution in Outfall	2:1 (min) 10:1 (max)	Uniform
	Dilution in Receiving Water	0 (min) 100:1 (max)	Log-Uniform

For SSOs, the volumes ingested employed in the simulations included 0.1 ml, 1 ml, 10 ml, and 100 ml. For CSOs, the volumes ingested employed in the simulations included 1 ml, 10 ml, 50 ml, and 100 ml. The ranges of volumes investigated were intended to account for exposures ranging from incidental contact (for SSOs) to body contact recreation (swimming) (for CSOs). The dilution of wastewater with stormwater within an outfall during a CSO event was assumed to vary from 2:1 to 10:1 (personal correspondence and best professional judgment). This variable was characterized with a uniform distribution in the numerical simulations. Additional dilution was assumed to also occur outside of the CSS outfall. These dilutions were assumed to range from zero additional dilution to 100:1. This variable was characterized with a log-uniform distribution in the numerical simulations.

3.3 Representative Concentrations of Pathogens in Environmental Waters and Stormwater

Bacterial indicator levels are commonly measured in stormwater samples under NPDES monitoring programs. Unfortunately, only limited data have been published in the scientific literature to date on microbial pathogen concentrations in CSOs or stormwater (Table 7). The limited amount of pathogen data available from CSOs and stormwater samples may be due to the fact that most receiving water standards are still based on bacterial indicator organism levels.

Because data were not available to specifically characterize the pathogen levels in stormwater, the analysis described herein is focused on the risk attributable specifically to the overflow (CSO or SSO) events.

Table 7 Overview of Pathogens in Environmental Waters and Stormwater

Pathogen Type	Pathogen	Range	Source	Notes
Virus	Rotavirus	2.4 X 10^{-1}/L	Rose et al. (1987)	surface water
		0.05 - 2.9 X 10^{1}/L	Gerba et al. (1996)	marine and freshwaters
	enteroviruses	0.1-6/10L	Griffin et al. (2003	marine water
		<0.01-0.24	MWRCD (2000, 1996, 1995, 1994)	urban fresh water
	reovirus	0.2-0.5/L	Griffin et al. (2003	Marine water
	adenovirus	8.8 X 10^{2} - 7.5 X 10^{3}L	Jiang et al. (2001)	PCR results: genomes/Liter
Protozoa	Cryptoporidium parvum	20 oocysts/L	States et al. (1997)	g. mean CSO discharge
		0.4 - 4/L (ICR) 0.1 - 0.8/L (EPA1623)	WWETCO (2003)	urban and rural creeks
		20 samples ND	Schroeder et al., (2002)	MDL ranged from 0.3-580oocysts/100mL
		130 cysts/L	Gibson et al. (1998)	mean, CSO discharge
	Giardia lamblia	20 samples ND	Schroeder et al., (2002)	MDL ranged from 0.3-580oocysts/100mL
		12-13/L (ICR) 0.35 - 3.75/L (EPA1623)	WWETCO (2003)	urban and rural creeks
		30-1000 cysts/L	Knauer et al. (1999)	CSO discharge
		150-300 cysts/L	Bowman (2002)	CSO discharge
		300 cysts/L	States et al. (1997)	g. mean CSO discharge
		600 cysts/L	Gibson et al. (1998)	mean, CSO discharge
Bacteria	Shigella	20 samples ND	Schroeder et al., (2002)	MDL ranged from 2.5-5000cfu/100mL
	Salmonella	<0.15 - 0.88/100mL	MWRCD (2001, 1999, 1997, 1996, 1995, 1994,	urban fresh water
		19/20 samples ND	Schroeder et al., (2002)	MDL ranged from 0.4-800cfu/100mL

4.0 RISK CHARACTERIZATION

4.1 Simulation Overview

Characterizing the potential adverse human health effects that may be associated with human exposure to pathogenic microorganisms in SSOs and CSO was carried out via numerical simulation. A static risk model stochastic simulation approach to account for the variability and uncertainty in each of the variables was employed to estimate the probability of adverse health effects from exposure to pathogens via overflow events.

To characterize the potential adverse human health effects that may be associated with human exposure to pathogenic microorganisms in SSOs, the variables employed included: the concentration of the pathogens of public health concern in raw wastewater (Table 3), the volume of water ingested (0.1 ml, 1.0 ml, 10 ml, and 100 ml), and the dose response parameters for the pathogens of public health concern in raw wastewater (Table 3).

To characterize the potential adverse human health effects that may be associated with human exposure to pathogenic microorganisms in CSOs, the variables employed included the concentration of the pathogens of public health concern in raw wastewater (Table 3), the volume of water ingested (1 ml, 10 ml, 50 ml, and 100 ml), the dose response parameters for the pathogens of public health concern in raw wastewater (Table 3), the dilution in the outfall that occurs during a CSO (Table 4), and the additional dilution that occurs in the receiving water after the CSO is discharged (Table 4).

In each numerical simulation, a value for each variable was selected randomly from the identified feasible range, and the probability of (illness or) infection was computed. This process was then repeated 5,000 times. The results of the simulations are presented below.

4.2 Numerical Simulation Results

4.2.1 Sanitary Sewer Overflows

The probabilities of infection or illness associated with each pathogen of public health concern from ingestion of SSO water at four assumed ingestion volumes (0.1 ml, 1 ml, 10 ml, 100 ml) are summarized below. Note that the characterization of risk associated with SSO events below does not include dilution of raw wastewater. It is understood that in fact, sometimes SSOs are diluted with either stormwater, receiving water, and/or potable water. In those cases, the potential risk attributable to the overflow event would more appropriately be estimated with the methodology presented in section 4.2.2.

Salmonella: The estimated attributable risk of *Salmonella* illness from an SSO event is presented in Figure 2. Inspection of Figure 2 indicates that the probability of *Salmonella* illness from exposure via an SSO ranges from 10^{-6} to 10^{-1}, depending on the volume of water ingested and the assumed concentration of *Salmonella* in raw wastewater. The substantial uncertainty presented in Figure 1 is derived directly from the uncertainty in the actual concentration of *Salmonella* in raw wastewater and volume of water ingested (Table 3). If it is assumed that the most likely

volume of water ingested is 1 ml, via incidental or accidental contact with the SSO water (refer to section 5.1.1), the median estimate of *Salmonella* illness is estimated to be approximately 10^{-4} (or 1 illness in 10,000 exposures).

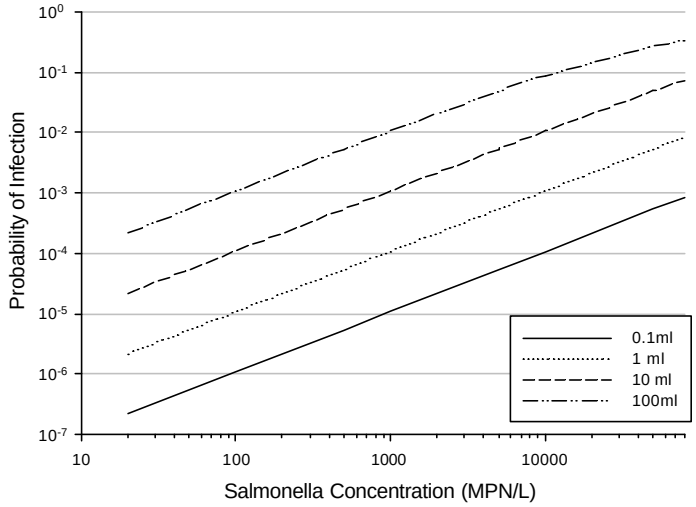

Figure 2 Probability of *Salmonella* Illness from Sanitary Sewer Overflow

Cryptosporidium and Giardia lamblia: The estimated attributable risks of *Cryptosporidium parvum* and *Giardia lamblia* infection from an SSO event are presented in Figures 3 and 4, respectively. Inspection of Figures 3 and 4 indicates that the probability of *Cryptosporidium parvum* and *Giardia lamblia* infection from an SSO exposure ranges from 10^{-6} to 10^{-1}, and 10^{-4} to 1 (10^{0}), *respectively* depending on the volume of water ingested and the assumed concentrations in raw wastewater. If it is assumed that the most likely volume of water ingested from an SSO is 1 ml (refer to section 5.1.1), the median estimates of *Cryptosporidium parvum* and *Giardia lamblia* infections are estimated to be approximately 10^{-4} (or 1 infection in 10,000 exposures) and 10^{-1} (or 1 infection in 10 exposures), respectively.

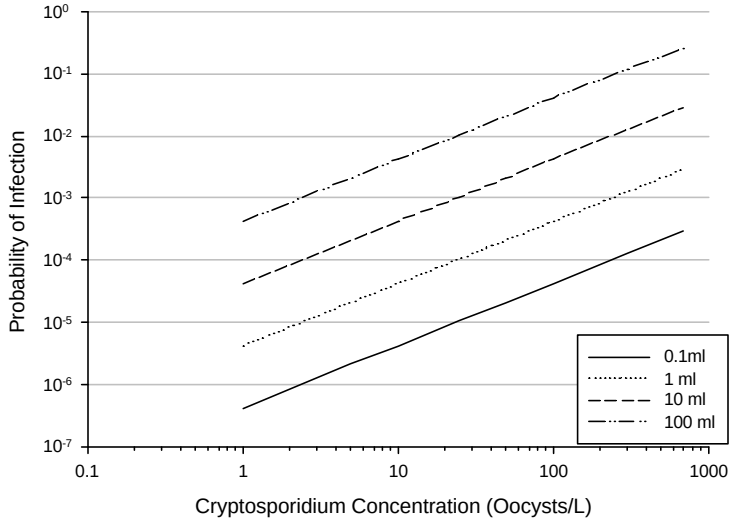

Figure 3 Probability of Cryptosporidium Infection from Sanitary Sewer Overflow

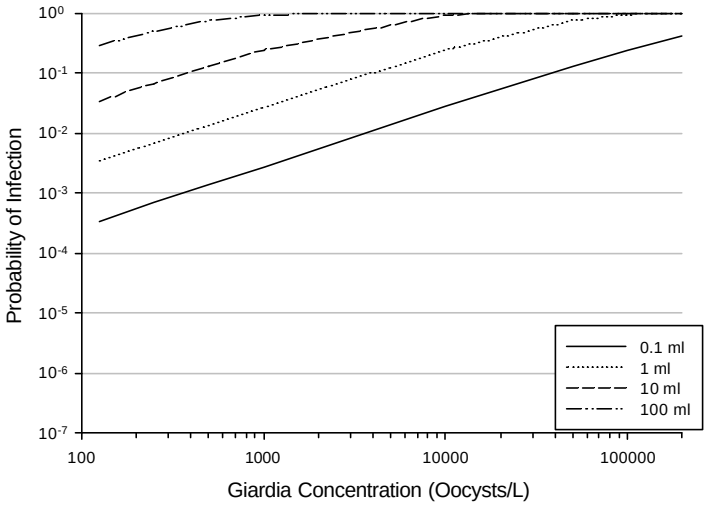

Figure 4 Probability of Giardia Infection from Sanitary Sewer Overflow

Enteric viruses: The estimated attributable risks of rotavirus and cumulative enteric virus infection from an SSO event are presented in Figures 5 and 6, respectively. Note that the cumulative enteric virus infection probability is derived from the probability of rotavirus infection and is scaled to account for the estimated total disease burden from enteric viruses, relative to the rotavirus disease burden (refer to Section 2.2.3). Inspection of Figures 5 and 6 indicates that the probability of rotavirus and cumulative enteric virus infection from an SSO exposure ranges from 10^{-5} to 10^{-1}, and 10^{-4} to 1 (10^{0}), respectively depending on the volume of water ingested and the assumed concentrations in raw wastewater. If it is assumed that the most likely volume of water ingested from an SSO is 1 ml, the median estimates of rotavirus and cumulative enteric virus infection are estimated to be approximately 10^{-2} (or 1 infection in 100 exposures) and 10^{-1} (or 1 infection in 10 exposures), respectively.

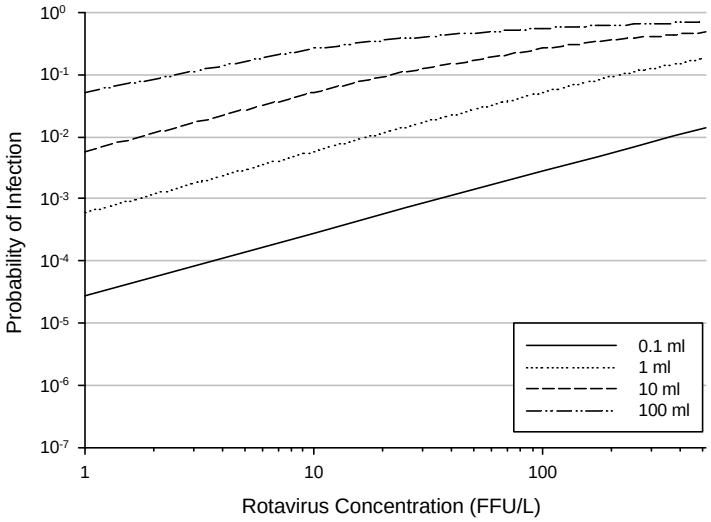

Figure 5 Probability of Rotavirus Infection from Sanitary Sewer Overflow

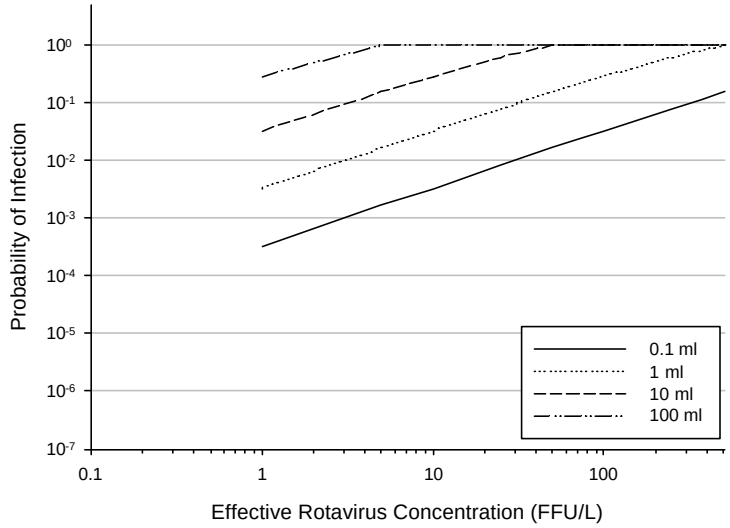

Figure 6 Probability of Enteric Virus Infection from Sanitary Sewer Overflow (derived from risk of Rotavirus infection)

Comparison of risks from pathogens of public health concern: A comparison of the estimated probability of infection for exposure to SSOs, for the pathogens of public health concern, is presented in Figures 7 through 10 for assumed ingestion volumes of 0.1 ml, 1.0 ml, 10 ml, and 100 ml, respectively (Note: estimated probabilities for *Salmonella* are for illness). The results are presented as probability plots with probability of infection displayed on the vertical axis and the percentage of observations less than the corresponding value shown on the horizontal axis. The median and 95th percentile values for the probability of infection for each of the pathogens at each of the ingestion volumes are summarized in Table 8.

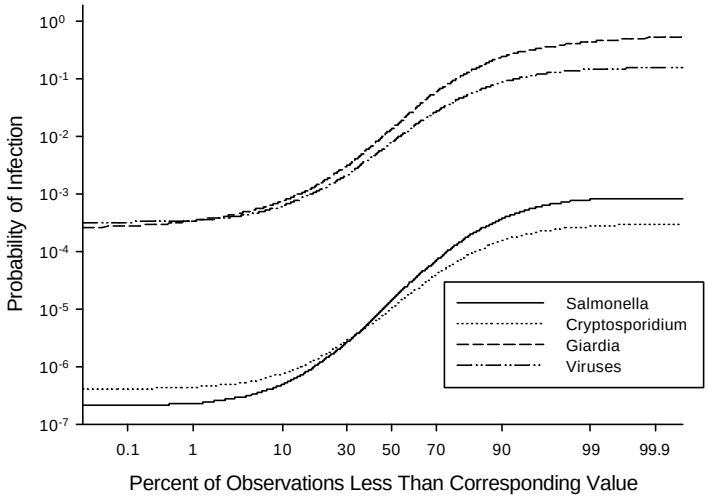

Figure 7 Probability of Infection from Exposure to Pathogens via an SSO Event (0.1 ml Ingestion)

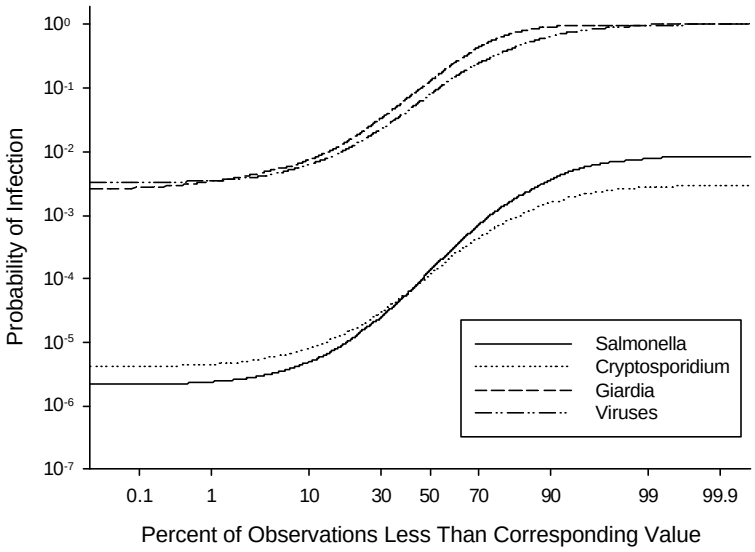

Figure 8 Probability of Infection from Exposure to Pathogens via an SSO Event (1ml Ingestion)

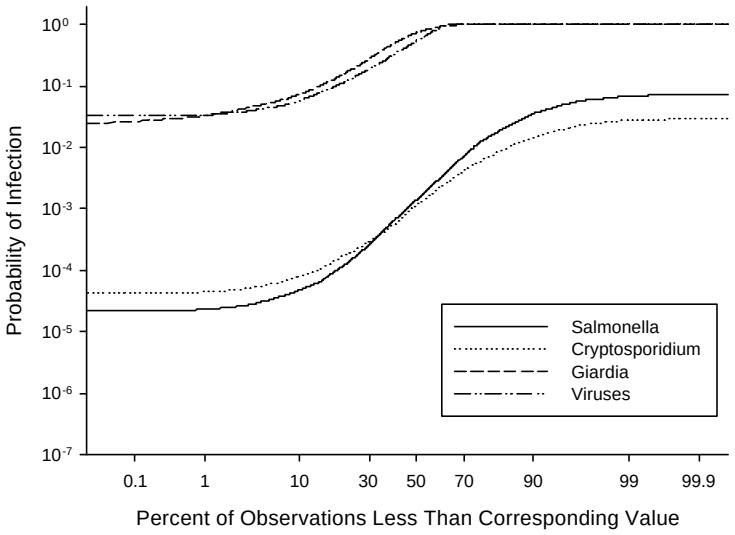

Figure 9 Probability of Infection from Exposure to Pathogens via an SSO Event (10ml Ingestion)

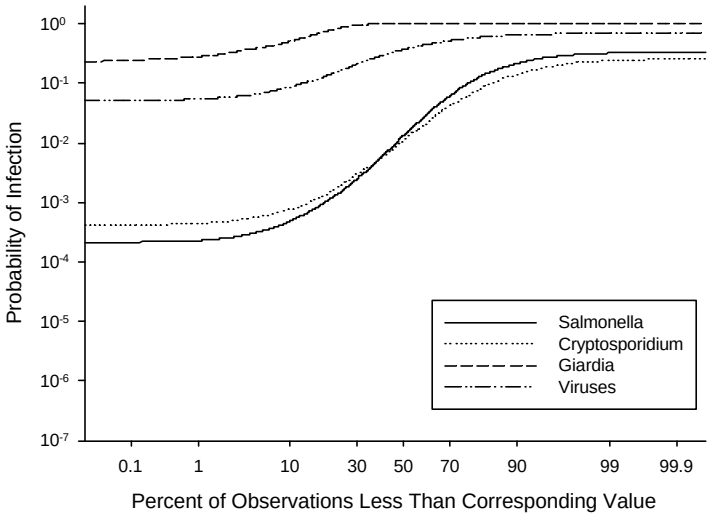

Figure 10 Probability of Infection from Exposure to Pathogens via an SSO Event (100ml Ingestion)

Inspection of Figures 7 through 10 and Table 8 indicates that the median probability of infection from exposure to an SSO for a given volume ingested is similar for salmonella and cryptosporidium parvum, and is also roughly similar for *giardia lamblia*, and enteric viruses. Not surprisingly, ingestion of 100 ml of SSO water (raw wastewater) results in a high median probability of infection (greater than 0.1) whereas ingestion of 0.1 ml results in a probability of infection on the order of 0.01.

Table 8 Summary of Estimated Probability of Infection for Range of Potential SSO Exposures

Volume		Probability of Infection	
Ingested (ml)	Pathogen	Median	95th Percentile
0.1	Salmonella	1E-5	6E-4
	Giardia	1E-2	3E-1
	Cryptosporidium	1E-5	2E-4
	Viruses	8E-3	1E-1
1	Salmonella	1E-4	6E-3
	Giardia	1E-1	1E+0
	Cryptosporidium	1E-4	2E-3
	Viruses	8E-2	8E-1
10	Salmonella	1E-3	5E-2
	Giardia	7E-1	1E+0
	Cryptosporidium	1E-3	2E-2
	Viruses	8E-1	1E+0
100	Salmonella	1E-2	3E-1
	Giardia	1E+0	1E+0
	Cryptosporidium	1E-2	2E-1
	Viruses	1E+0	1E+0

Note: 1E-5 = 1×10^{-5}

Probabilities shown for Salmonella are for illness

4.3.2 Combined Sewer Overflows

The estimated probabilities of infection associated with each pathogen of public health concern from ingestion of CSO water at four assumed ingestion volumes (1 ml, 10 ml, 50 ml, 100 ml) are summarized below. For each combination of pathogen and assumed volume, the results of the numerical simulations are presented in graphical format illustrating how the probability of infection is related to the total dilution. (Note that dilution is assumed to occur in two different forms: in the outfall ranging from 2:1 to 10:1, and outside of the outfall ranging from 0 additional dilution to 100:1 additional dilution). The results shown (Figures 11 through 26) present the regression line and the 95% confidence interval of the regression line for the relation between dilution and the estimated probability of infection. The width of the confidence interval around the regression line indicates the associated uncertainty. The uncertainty in those estimates is derived from the concentration of the pathogen in raw wastewater.

Salmonella: The risk of salmonella illness from exposure via a CSO event is presented in Figures 11 through 14 for assumed ingestion volumes of 1 ml, 10 ml, 50 ml, and 100 ml, respectively. Inspection of Figure 11 indicates that for an assumed ingestion of 1 ml, the mean probability of *Salmonella* illness from exposure via a CSO ranges from 10^{-8} to 10^{-4}, depending on the level of dilution. At any given level of dilution, the 95% confidence interval about the mean estimate spans approximately 4 orders of magnitude. Inspection of Figures 12 through 14 indicates that the probability of illness increases with the assumed ingestion volume.

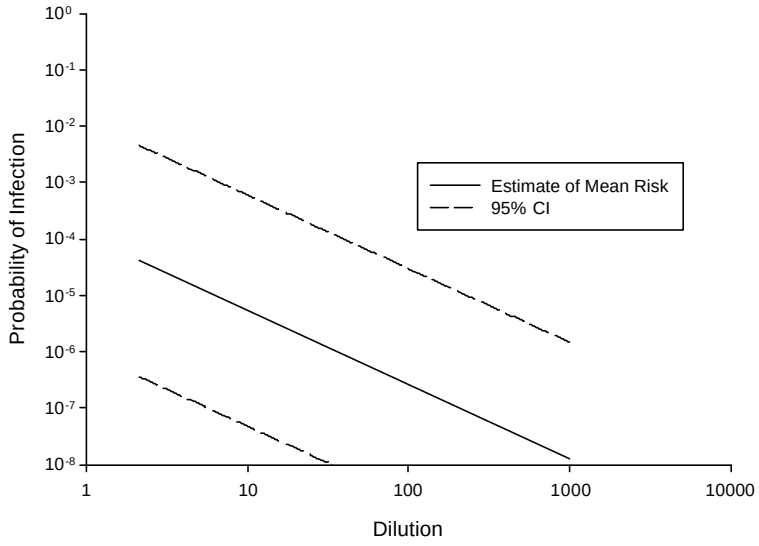

Figure 11 Probability of *Salmonella* Illness from CSO (1 ml Ingestion)

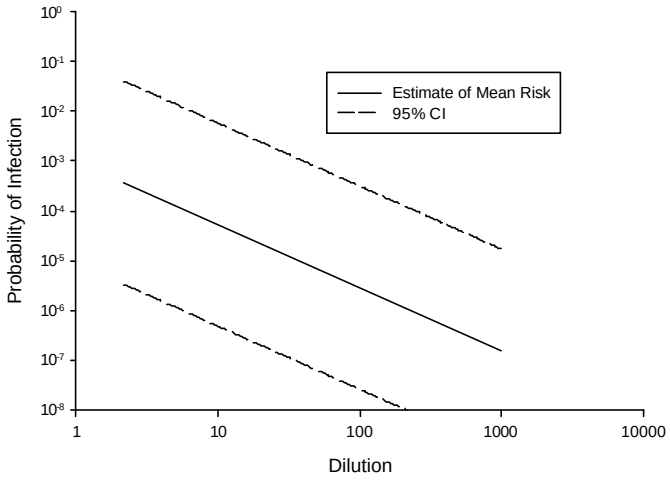

Figure 12 Probability of *Salmonella* Illness from CSO (10 ml Ingestion)

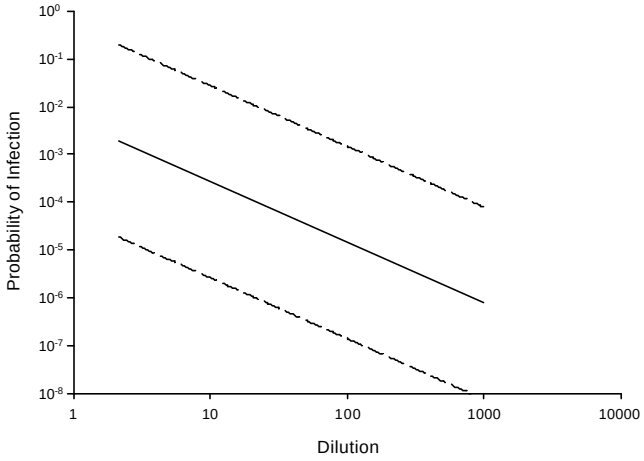

Figure 13 Probability of *Salmonella* Illness from CSO (50 ml Ingestion)

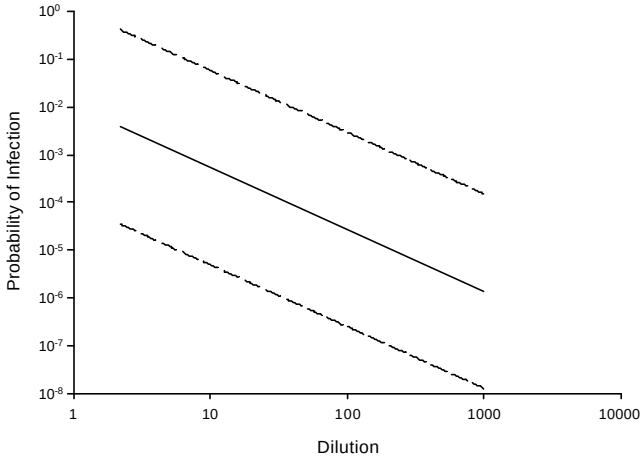

Figure 14 Probability of *Salmonella* Illness from CSO (100 ml Ingestion)

Cryptosporidium: The estimated risk of *Cryptosporidium* infection from exposure via a CSO event is presented in Figures 15 through 18 for assumed ingestion volumes of 1 ml, 10 ml, 50 ml, and 100 ml, respectively. Inspection of Figure 15 indicates that for an assumed ingestion of 1 ml, the mean probability of *Cryptosporidium* infection from exposure via a CSO ranges from 10^{-8} to 10^{-4}, depending on the level of dilution. At any given level of dilution, the 95% confidence interval about the mean estimate spans approximately 3 orders of magnitude. Similar to the results for *Salmonella*, the probability of infection increases with the assumed ingestion volume.

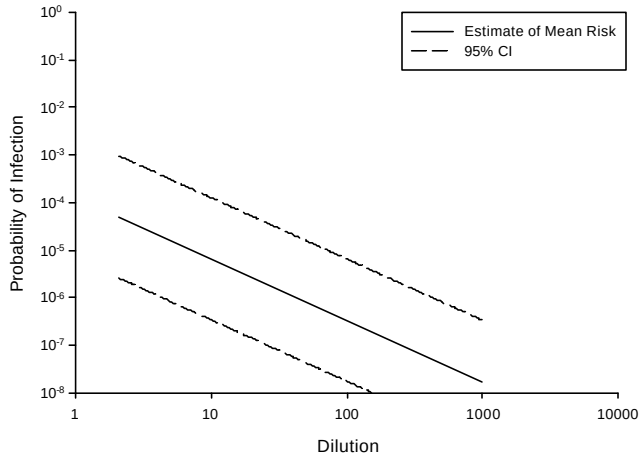

Figure 15 Probability of Cryptosporidium Infection from CSO (1 ml Ingestion)

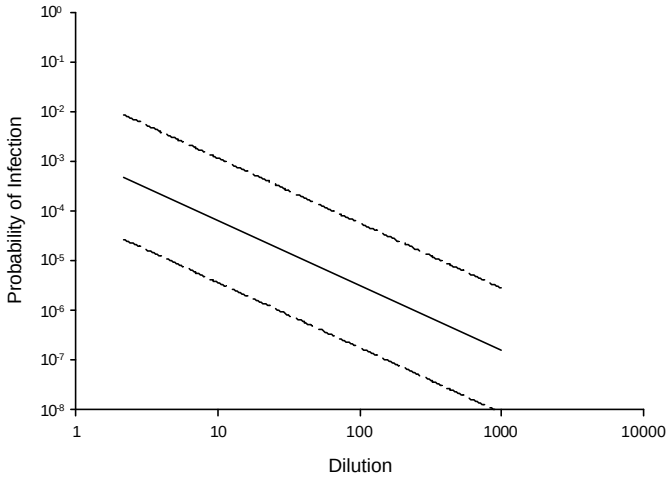

Figure 16 Probability of Cryptosporidium Infection from CSO (10 ml Ingestion)

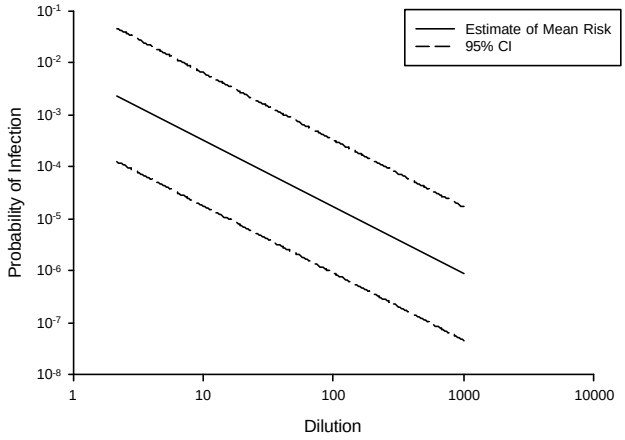

Figure 17 Probability of Cryptosporidium Infection from CSO (50 ml Ingestion)

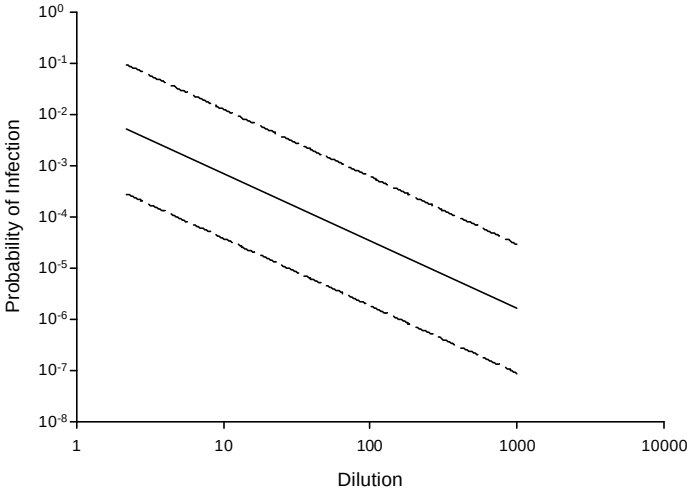

Figure 18 Probability of Cryptosporidium Infection from CSO (100 ml Ingestion)

Giardia: The estimated risk of *Giardia lamblia* infection from exposure via a CSO event is presented in Figures 19 through 22 for assumed ingestion volumes of 1 ml, 10 ml, 50 ml, and 100 ml, respectively. Inspection of Figure 19 indicates that for an assumed ingestion of 1 ml, the mean probability of *Giardia* infection from exposure via a CSO ranges from 10^{-3} to 10^{-1}, depending on the level of dilution. At any given level of dilution, the 95% confidence interval about the mean estimate spans up to approximately 6 orders of magnitude. The probability of infection increases with the assumed ingestion volume, with the caveat that the upper 95% confidence interval does not strictly increase with increased ingestion volumes since the probability of infection is bounded (i.e. must be less than or equal to one).

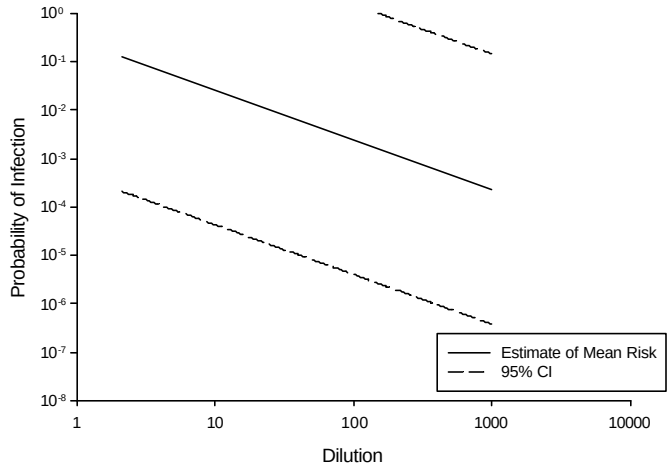

Figure 19 Probability of Giardia Infection from CSO (1 ml Ingestion)

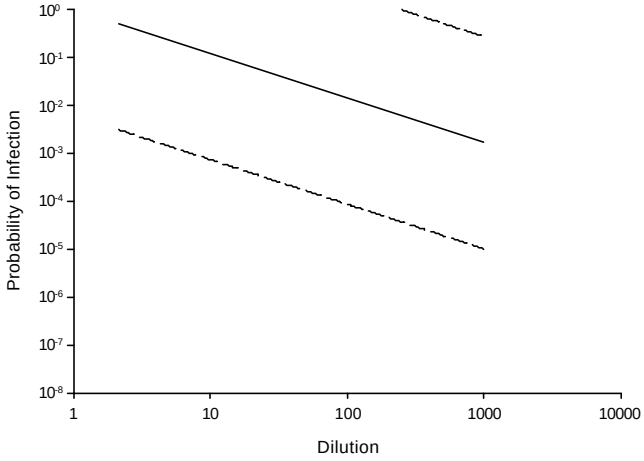

Figure 20 Probability of Giardia Infection from CSO (10 ml Ingestion)

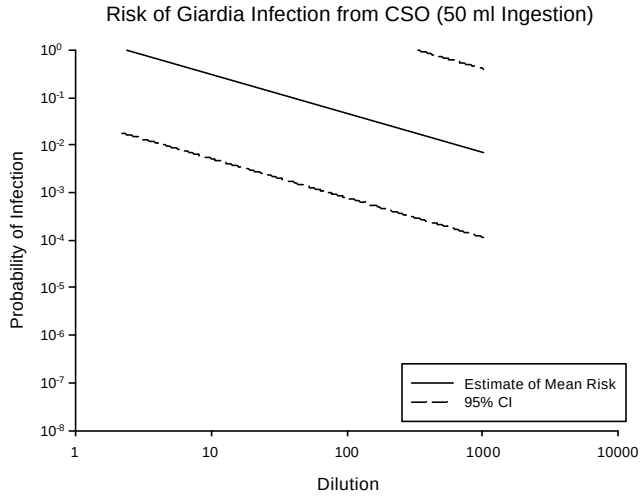

Figure 21 Probability of Giardia Infection from CSO (50 ml Ingestion)

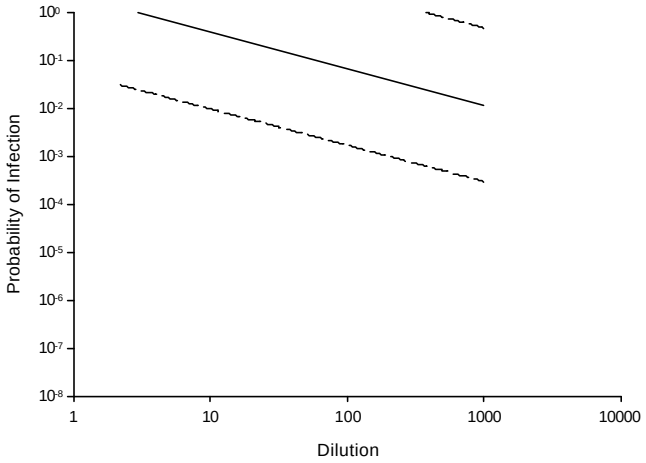

Figure 22 Probability of Giardia Infection from CSO (100 ml Ingestion)

Enteric viruses: The estimated risk of enteric virus infection from exposure via a CSO event is presented in Figures 23 through 26 for assumed ingestion volumes of 1 ml, 10 ml, 50 ml, and 100 ml, respectively. Inspection of Figure 23 indicates that for an assumed ingestion of 1 ml, the mean probability of enteric virus infection from exposure via a CSO ranges from 10^{-5} to 10^{-1}, depending on the level of dilution. At any given level of dilution, the 95% confidence interval about the mean estimate spans up to approximately 3 orders of magnitude. Similar to the results presented previously, the probability of infection increases with the assumed ingestion volume, with the caveat that the upper 95% confidence interval does not strictly increase with increased ingestion volumes above 10 ml since the probability of infection is bounded at 1.0.

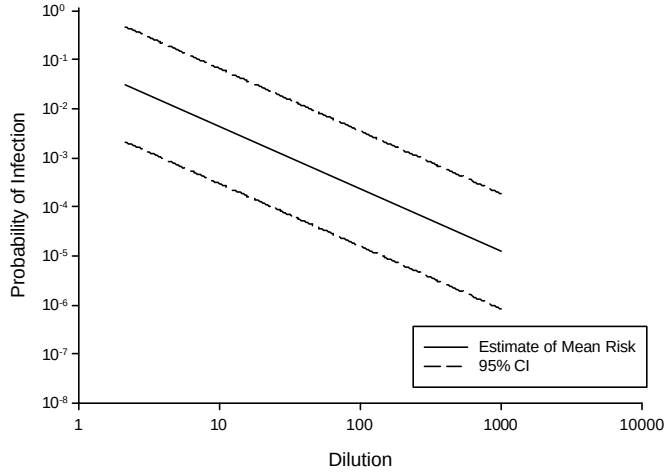

Figure 23 Probability of Enteric Virus Infection from CSO (1 ml Ingestion)

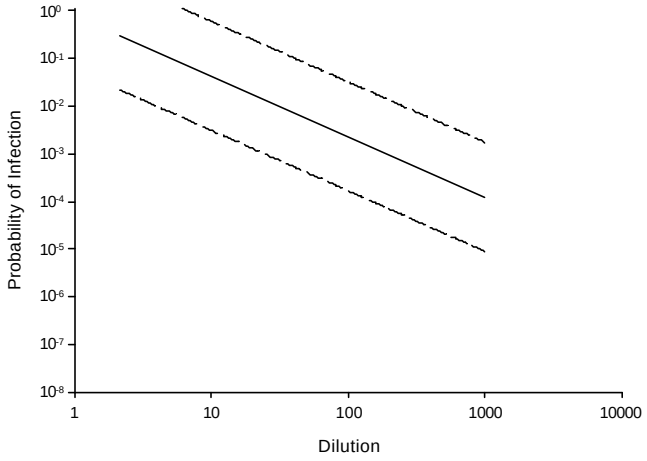

Figure 24 Probability of Enteric Virus Infection from CSO (10 ml Ingestion)

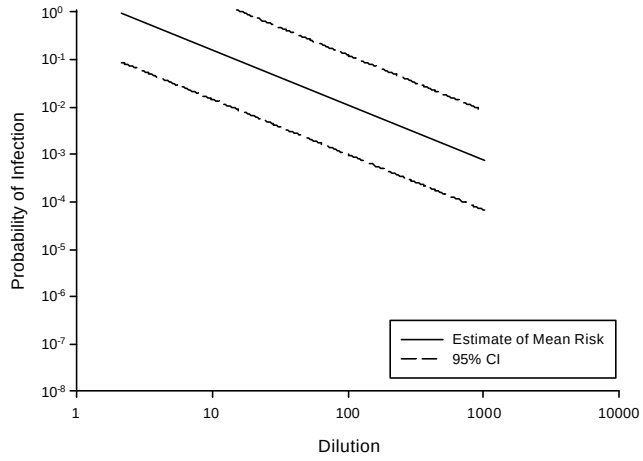

Figure 25 Probability of Enteric Virus Infection from CSO (50 ml Ingestion)

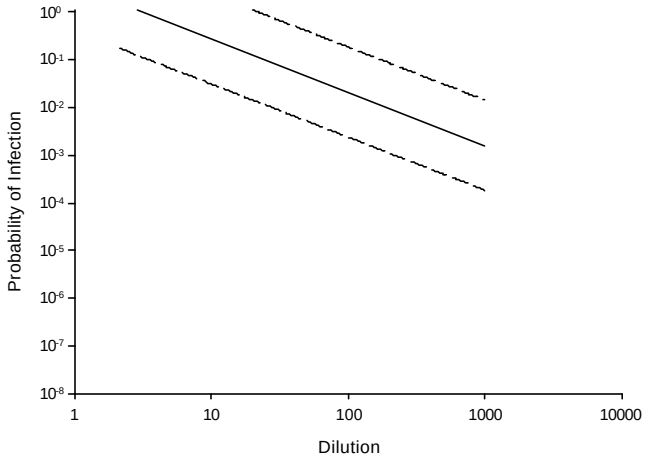

Figure 26 Probability of Enteric Virus Infection from CSO (100 ml Ingestion)

Comparison of risks from pathogens of public health concern: A comparison of the estimated mean probability of infections for exposure to CSO waters, for the set of pathogens of public health concern is presented in Figures 27 through 30 for assumed ingestion volumes of 1ml, 10ml, 50ml, and 100ml, respectively (Note that the 95% confidence intervals are not presented on these figures. The uncertainty associated with the estimates are presented above in Figures 11 through 26). The results present the probability of infection for each of the pathogens of public health concern as a function of total estimated dilution at the specified ingestion volumes (Note that results shown for *Salmonella* are probability of illness).

For example, the probability of infection from exposure to pathogens of public health concern via a CSO event with an assumed ingestion volume of 1 ml is presented in Figure 27. Similarly, the probability of infection for an assumed ingestion volume of 10 ml is presented in Figure 28. A summary of the results from Figures 27 through 30 is presented in Table 9. Note that data to validate the volumes consumed during actual exposures are not available from the literature, however, ingestion of 100mL is often assumed for recreational contact exposures (Haas 2000).

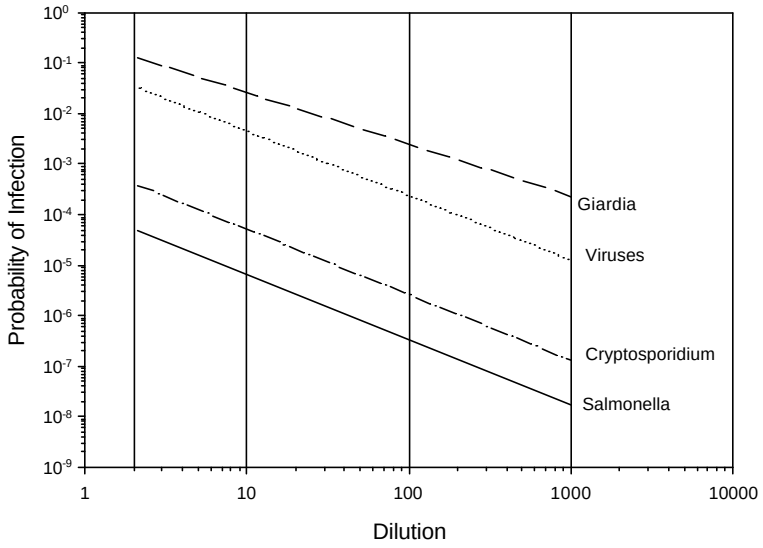

Figure 27 Probability of Infection from Exposure to Pathogens via a CSO Event (1 ml ingestion)

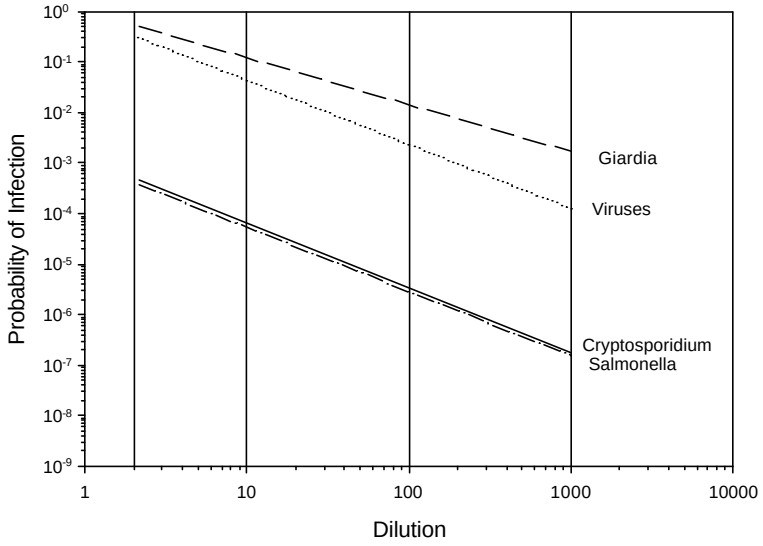

Figure 28 Probability of Infection from Exposure to Pathogens via a CSO Event (10 ml ingestion)

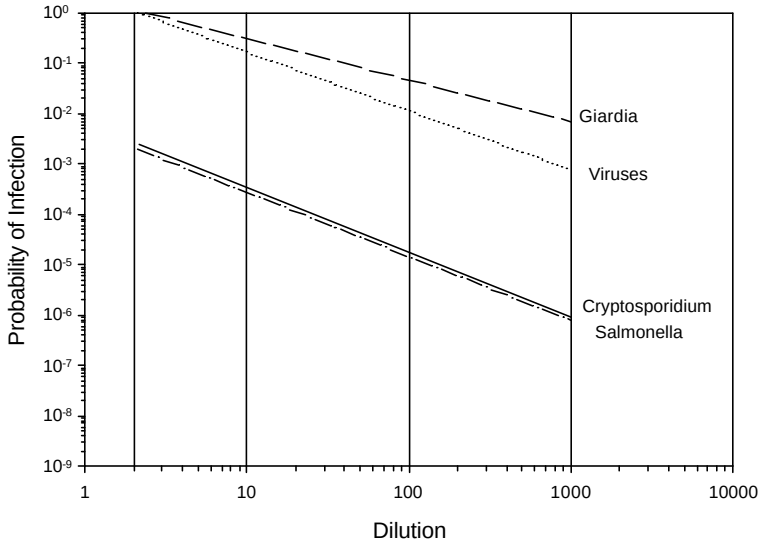

Figure 29 Probability of Infection from Exposure to Pathogens via a CSO Event (50 ml ingestion)

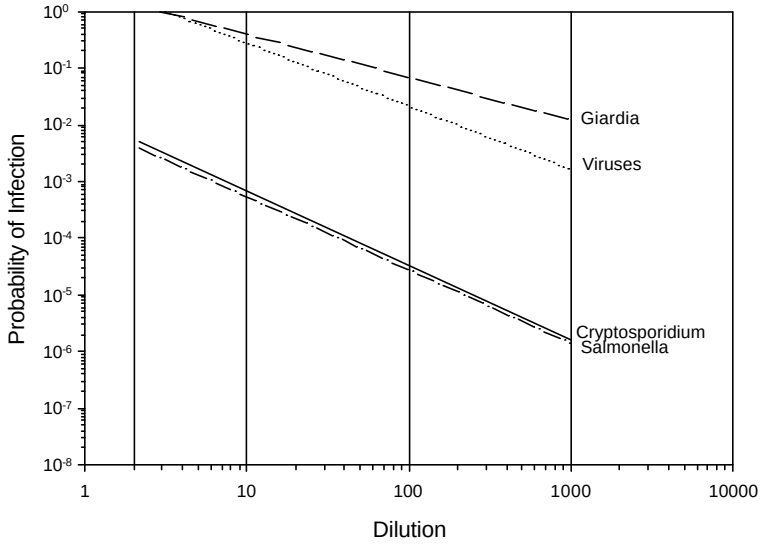

Figure 30 Probability of Infection from Exposure to Pathogens via a CSO Event (100 ml ingestion)

Table 9 Summary of Estimated Probability of Infection for Range of Potential CSO Exposures

		Probability of Infection			
Volume		Dilution			
Ingested	Pathogen	2:1	10:1	100:1	1000:1
100ml	Salmonella	5E-3	6E-4	4E-5	2E-6
	Giardia	1E+0	5E-1	8E-2	2E-2
	Cryptosporidium	6E-3	7E-4	4E-5	2E-6
	Enteric Viruses	1E+0	3E-1	3E-2	2E-3
50ml	Salmonella	2E-3	3E-4	2E-5	1E-6
	Giardia	1E+0	4E-1	5E-2	7E-3
	Cryptosporidium	3E-3	4E-4	2E-5	1E-6
	Enteric Viruses	1E+0	2E-1	1E-2	9E-4
10ml	Salmonella	4E-4	6E-5	4E-6	2E-7
	Giardia	6E-1	1E-1	2E-2	3E-3
	Cryptosporidium	5E-4	7E-5	6E-6	2E-7
	Enteric Viruses	4E-1	5E-2	3E-3	2E-4
1ml	Salmonella	4E-5	5E-5	4E-6	2E-7
	Giardia	1E-1	3E-2	3E-3	3E-4
	Cryptosporidium	5E-5	7E-6	4E-7	3E-8
	Enteric Viruses	3E-2	5E-3	3E-4	2E-5

Note: 1E-5 = 1 x 10^{-5}

Probabilities shown for Salmonella are for illness

5.0 DISCUSSION

5.1 Discussion of Simulation Results

Numerical simulations were carried out to estimate the potential public health risk associated with exposure to microbial pathogens via CSO and SSO events. The results of the simulations represent estimations of the theoretical probability of illness/infection for a single exposure event for an individual. A static screening-level model for microbial risk assessment was employed to develop the estimations of risk. Processes specific to the transmission of infectious diseases such as person to person transmission (secondary spread) and immunity from infection are assumed to be negligible in this type of static individual-based analysis. Following is a discussion of the simulation results for SSOs and CSOs, as well as a brief summary of the limitations of the investigation. Interpretation of the simulation results is discussed in section 5.2.

5.1.1 Discussion of Simulation Results for Sanitary Sewer Overflows

The variables employed in the SSO simulations included the concentration of pathogens of public health concern in raw wastewater, the volume of SSO ingested, and infectivity of the pathogens.

Variability and Uncertainty: Associated with each of the variables investigated, was both variability and uncertainty. In the case of the SSO volume ingested, estimates are based on best professional judgment as data are not available in the literature to quantify this variable. The estimates of risk do not account for variability in pathogen viability or recovery efficiency of methods employed. Depending on the viability and recovery efficiencies from the cited studies, the risks associated with these pathogens could either be higher or lower than estimated herein. Infectivity is typically determined based on human feeding studies of healthy adult volunteers. The need to address differential susceptibility within the population with respect to infection from pathogenic microorganisms is a topic of current research. At this point in time, with respect to infectivity the only viable option (from a risk assessment perspective) is to employ critically reviewed dose-response data, as was carried out herein (Parkin et al. 2003).

Exposure Volume: The numerical simulations presented for SSOs represent exposure conditions in which individuals were assumed to have ingested volumes of SSO water (untreated wastewater) ranging from 0.1 ml to 100 ml. Interpretation of the simulation results requires that the likely volume of water ingested be considered carefully. Given that for this investigation, SSOs are treated (numerically) as undiluted wastewater, it may reasonable to infer that the most likely exposure scenarios would be comprised of accidental or incidental contact with the SSO. That being the case, the estimates of risk generated herein based on the lower end of the volume ingested range (0.1ml or 1.0 ml), may represent the most likely exposures.

Dominant Risks: The results of the numerical simulations for SSOs suggest that the probability of infection from exposure to SSOs is dominated by *Giardia lamblia* and enteric viruses (Table 8). It was reported previously that *Shigella* was not included in these analyses because of the uncertainty in the available data. Regardless of the uncertainty surrounding the *Shigella* results, the relative consistency of the results between *Giardia lamblia* and enteric viruses does provide a base from which risk management decisions could stem (Section 5.2).

5.1.2 Discussion of Simulation Results for Combined Sewer Overflows

In the numerical simulations that were carried out to estimate the risks to human health from exposure to pathogens via exposure to CSO events, the variables employed included: the concentration of pathogens of public health concern in raw wastewater, the volume of CSO water ingested, pathogen infectivity, the dilution in the outfall during the CSO event, and the additional dilution that occurs outside of the outfall (i.e. in the receiving water).

Variability and Uncertainty: Similar to the discussion presented above for the SSO simulations, there was both variability and uncertainty associated with each of the variables employed in the numerical simulations. For the variables that were employed in both SSO and CSO simulations (the concentration of pathogens of public health concern in raw wastewater, the volume ingested, and pathogen infectivity), the points of discussion highlighted in section 5.1.1 apply for the CSO simulations also. In addition to those factors, dilution played a critical in the CSO simulations.

Comparing the results of the literature review for pathogen concentrations in environmental waters and stormwater (Table 7), and the reported concentrations of *Giardia lamblia* raw wastewater (Table3), it seems likely that the levels of dilution investigated herein are reasonably representative of CSO events, given the limited available data.

Exposure Volume: The numerical simulations presented for CSOs represented exposure conditions in which individuals were assumed to have ingested volumes of CSO water ranging from 1ml to 100ml. Data were not available from the literature to accurately characterize the expected level of water ingested from a CSO event. However, it seems reasonable to apply a health protective assumption that the worst reasonable case of exposure would be individuals recreating in a surface water that receives the CSO. In this case, the estimates of risk generated herein based on the upper end of the volume ingested range (50 ml or 100 ml) may represent reasonable exposures (U.S. EPA 1989).

Dominant Risks: The results of the numerical simulations for CSOs suggest that the probabilities of infection from exposure to CSOs are dominated by *Giardia lamblia* and enteric viruses, as was also the case with SSOs. Interestingly, at low dilution ratios the risk of infection from *Giardia lamblia* and enteric viruses was similar for all ingestion volumes investigated (Figures 27 through 30). However, as the dilution ratio increases, the risk of infection from *Giardia lamblia* begins to overshadow the of enteric virus infection. In all cases the risks of infection from *Salmonella spp*. and *Cryptosporidium parvum* are predicted to be well below that of *Giardia lamblia* or enteric viruses.

5.1.3 Limitations

The quantitative characterization of potential health risks associated with CSOs and SSOs is limited by the data available to characterize the variables employed in the numerical simulations. The data limitations encountered during this investigation include pathogen occurrence data in wastewater (most notably for Norwalk-like viruses and *Shigella*) and stormwater (for most pathogens), human dose-response data for Norwalk-like viruses, accurate estimates of human exposure data to SSO and CSO events, and dilution data during CSO events.

A further limitation of the data that were available to characterize the concentration of pathogens in raw wastewater is that the viability of the organisms and the laboratory recovery efficiency was not accounted for in most cases. As noted previously, these two factors would impact the risk characterizations presented herein in opposite ways (accounting for viability would likely decrease the computed risk of infection and accounting for recovery efficiency would likely increase the computed risk of infection). The extent to which these factors bias the results reported herein is unknown.

To the maximum extent feasible, the best available scientific and technical data were compiled and employed during this investigation. Where those data were not sufficient, anecdotal information based on conversations with experienced municipal staff were used to develop best professional judgment estimations (for example, dilution estimates for CSO). Given the uncertainty in the available data and that some data were based on subjective and/or imperfect information, the resulting analysis must be interpreted within a screening level context and extrapolation beyond that context is not suggested.

The health outcome associated with infection and disease in this investigation was gastroenteritis. There are a number of other more serious disease outcomes that are also associated with pathogenic microorganisms and characterizing the risk associated only with gastroenteritis likely under estimates the true cumulative risk to public health. Characterizing other endpoints more serious than gastroenteritis was beyond the scope of this investigation, however the likelihood for such health outcomes are important, should be considered during the risk management process, and should be the focus of future research.

5.2 Interpretation of Simulation Results and Risk Management Considerations

The simulation results presented in Section 4 represent the theoretical probabilities of infection/illness to an individual from a single exposure to an SSO or CSO event, based on specified levels of ingestion and/or dilution (in the case of a CSO). While these numerical estimations provide a gauge from which potential risk to an individual may be evaluated for a single exposure event, for risk management purposes, the number of people exposed to CSO and SSO events must also be taken into consideration. Risk of infection/disease from a single exposure event above some predetermined tolerable level does not necessarily imply that public health concern is warranted[3].

The protection of public health clearly dictates that when more individuals are potentially exposed to pathogens, a greater level of concern and thus protection is warranted when making risk management decisions. For example, one reason that a risk manager may decide to implement a control strategy at a specific location over another could be based on the actual or expected number of individuals potentially exposed during CSO events.

[3] The expected number of "cases" from an exposure event can be thought of as the product of the probability of illness (or infection) and the number of people exposed. It is within this paradigm that occupational exposure standards (lower number of people exposed) for hazardous substances may be many times higher than levels acceptable for the general population (higher number of people exposed).

Previous water quality regulation strategies endorsed by U.S. EPA follow the public health principle introduced above. In the Ambient Water Quality Criteria for Bacteria (U.S. EPA 1986), EPA defines an acceptable swimming associated gastroenteritis (illness) rate and derives water quality criteria for designated beach areas, moderately used full body contact recreation areas, lightly used full body contact recreation areas, and infrequently used full body contact recreation areas. As specified by U.S. EPA, the acceptable swimming associated gastroenteritis (illness) rate is 8/1000 for freshwater and 19/1000 for marine waters (approximately 1 illness per 100 recreation events). EPA's derivation of indicator bacteria limits based on the acceptable illness rate results in a maximum allowable density of indicator bacteria that increases as the potential number of exposed individuals decreases.

Assuming that EPA's acceptable swimming associated illness rate is a reasonable benchmark from which risk management decisions may be derived relative to public health concern related to sewer overflows, this provides a mechanism to interpret the results presented in Section 4.0 within a public health framework. For example, by using an approximate acceptable illness rate of 1/100 events, it is possible to assess on a screening level whether the estimated illness rates from exposures to CSOs are above the acceptable level of risk, close to (above or below) the acceptable level of risk, or substantially below the acceptable level of risk (Figure 31). The line presented in Figure 31 conceptually separates the scenarios that are above the acceptable level of risk from those that are near or below the acceptable level of risk. Note that the difference between the rate of illness and the rate of infection is employed as an additional margin of safety in Figure 31.

Inspection of Figure 31 indicates that exposures to pathogens from CSO events with low dilution rates result in computed probability of illnesses (risks) that are above which EPA considers tolerable for swimming activities. As dilution increases the risk associated with activities that would result in higher volumes of water ingested converges with the "acceptable" level of risk. At dilution ratios of 1000:1 and greater, the risks associated with activities that would involve 100 ml of ingestion or less are all near or below the acceptable risk level for swimming activities.

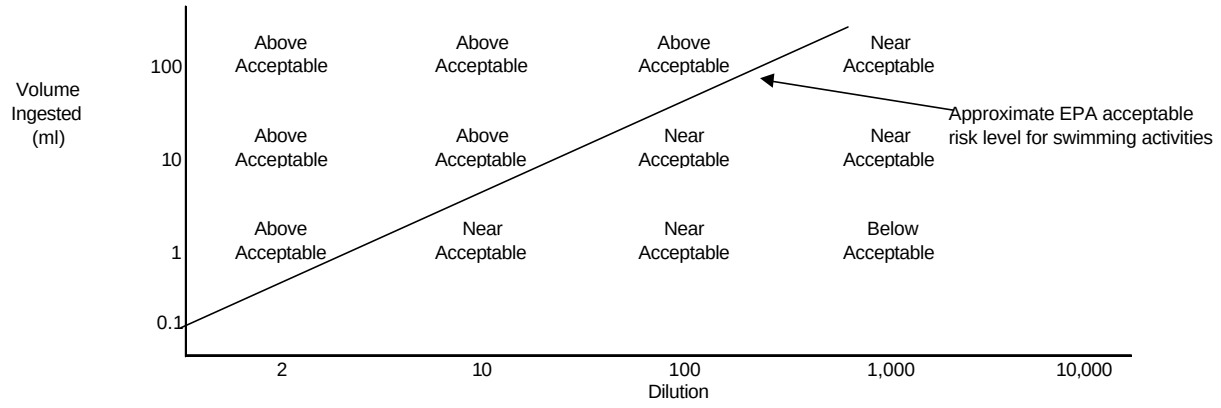

Figure 31 Comparison of EPA's Acceptable Illness Rate for Swimming with Estimated CSO Probability of Illness

Consistent with the public health tenet set forth above and EPA's strategy for deriving water quality criteria, it is conceptually possible to develop a series of lines that qualitatively separate scenarios that are above the acceptable level of risk from those that are near or below the acceptable level of risk for decreasing levels of exposure. One such conceptualization is

presented in Figure 32. In Figure 32, areas to the left of each of the lines represent scenarios that would be expected to be above the acceptable level of risk for that particular level of use (relative number of individuals exposed), and areas to the right of each of the lines represent scenarios that would be expected to be near or below the acceptable level of risk for that particular level of use.

The concepts set forth in Figure 32 are intuitively consistent with public health protection and conceptually straightforward. For example, consider a sewer overflow event that results in little dilution and is located near an area which supports a light level of recreational activity (Example 1, Figure 32). Inspection of Figure 32 indicates that such a scenario would likely be cause for public health concern should exposure occur, and thus may require some action (beach closing or implementation of another control measure to reduce exposure, for example). Similarly if a overflow event with a substantial amount of dilution (for example >100:1) occurred at the same beach, the level of public health concern may be somewhat diminished (Example 2, Figure 32). As a final example consider an SSO (little to no dilution) located in an area that results in only incidental contact by very few people (Example 3, Figure 32). Inspection of Figure 32 indicates that such an event would likely not be cause for public health concern. If on the other hand the SSO occurred in an area where an activity resulted in a higher level of exposure, more public health concern may be warranted.

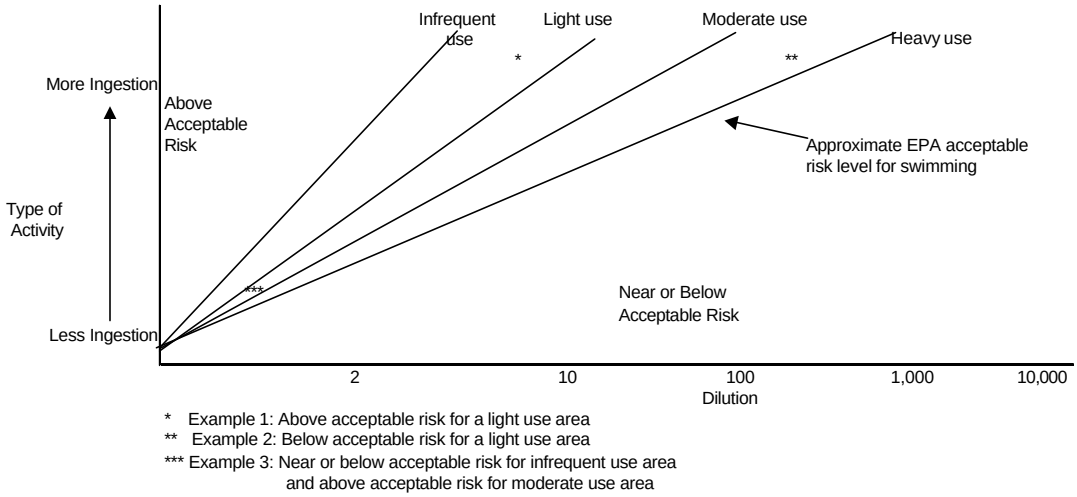

Figure 32 Conceptual Relation Between Risk Associated with Sewer Overflows and Relative Number of Exposed Individuals

Because of the substantial uncertainties involved with available data, converting the qualitative concepts presented above into a quantitative risk based analysis does not seem possible at this time. However, it seems likely that the strategies laid out in Figures 31 and 32 are sufficiently developed that they should be considered as part of risk management decisions. For example, this type of strategy could be used within a regulatory environment as a tool to prioritize and evaluate the potential human health impact of CSOs and SSOs and to assist in determining where public resources could be most effectively used to implement control or response strategies aimed at minimizing those potential impacts.

Finally, future research could be aimed at reducing some of the data gaps and/or uncertainties identified herein. Such refinement could in turn lead to better characterizations of risk that potentially could be used to refine Figure 32. Several potential research topics likely to add additional insight to this subject include occurrence and infectivity of Norwalk-like viruses, case specific information for characterizing the range of potentially exposed populations, ranges of dilution that occur in CSOs and wet weather SSOs, and concentrations of pathogens in stormwater and receiving waters.

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