Northeast Creek TMDL: The health and economic impact of high concentrations of fecal coliform.

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Abstract

Forty years after the passage of the Clean Water Act, 40% of the nation's waterways still do not meet water quality standards. In order to achieve the Clean Water Act's goals, the Environmental Protection Agency implemented the Total Maximum Daily Load (TMDL) program. A TMDL is a quantitative representation of pollution contribution from point and non point sources and is often used as part of watershed restoration plans. Watershed restoration plans involve implementing strategies and policies that can effectively achieve water quality standards; since TMDLs only provide information about the sources, they're use is limited. The addition of a health risk component identifies the costs from current contaminant levels, and the benefits from achieving compliance standards, thus allowing policy makers to choose the most efficient and cost effective restoration strategies. This research addresses the impact of high fecal colifrom concentrations in Northeast Creek, identifying both an economic and health impact, associated with either the baseline (no policy) or establishment of a TMDL.

INTRODUCTION:

In 1972 the United States government, in response to public concern about the conditions of the nation's waters, enacted the Federal Water Pollution Control Act Amendments of 1972. With additional amendments in 1977, the Act became known as the Clean Water Act (CWA) of 1977 (NRDC 2003). The CWA expanded and built upon the previous laws that were designed to control and prevent water pollution. Provisions of the CWA placed the Environmental Protection Agency (EPA) in charge of monitoring and maintaining the quality of the nation's waters. The EPA administered and defined water quality standards per use (i.e. recreation, drinking, transportation) for the states, tribes, and governing bodies (USEPA 2006). Even with all of the provisions, 40 years later many of the nation's water bodies do not meet water quality standards for their specified use (USEPA 2006).

Today, over 40% of the nation's waters are still considered impaired, leaving over 200 million citizens living within a 10-mile radius of an impaired water body (USEPA 2006). Defining water quality standards alone has not achieved compliance, so the EPA, under section 303(d) of the CWA, implemented both a point and nonpoint Total Maximum Daily Load (TMDL) program (USEPA 2006) to also control sources of contaminants entering water bodies. A TMDL is the maximum amount of a pollutant that a water body can receive daily and still meet water quality standards.

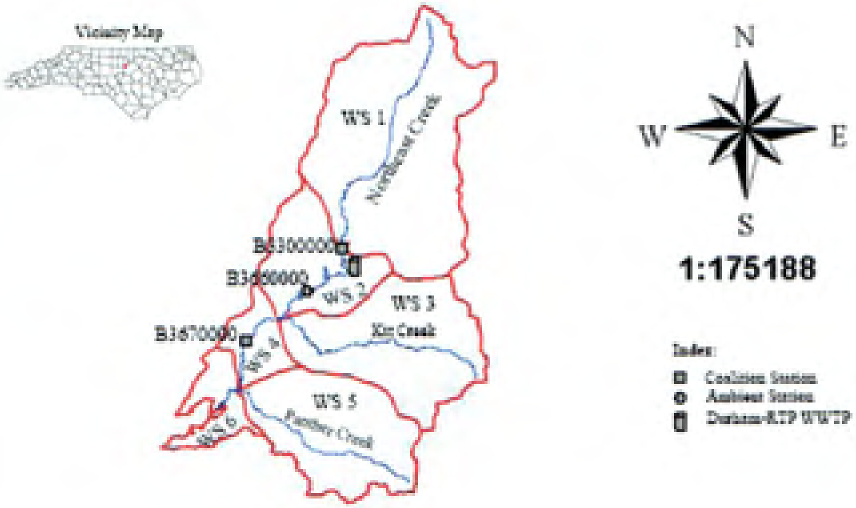
In order to restore the nation's waters, the EPA requires each state to create a TMDL for each impaired water body. To meet TMDL standards, states have the flexibility of implementing a combination of strategies and policies that help reduce the pollutant concentrations and meet water quality standards. The flexibility in the TMDL approach has helped reduce the number of impaired water bodies, but still does not capture all the complexities associated with meeting water quality standards. Very often TMDLs are used as part of larger watershed restoration plans, in which communities have to choose strategies and policies that achieve compliance the most cost effectively; but one cost that is rarely considered is the cost of noncompliance of a waterbody due to decreases in public health. In order to have more effective policy and strategy selection, attention must be paid not only to the cost of bringing a waterbody into compliance but also the costs of noncompliance and benefits of load reduction in terms of public health.

One way to create a more comprehensive and defensible TMDL plan therefore is through the addition of a health risk assessment component. A health risk assessment can add qualitative and quantitative characterizations and estimations of potential adverse health effects associated with exposure of individuals or populations to hazards (materials, situations, and physical, chemical or microbial agents) (Haas et al 1999). In addition, a health risk assessment added for a TMDL strategy can help place emphasis on the health and economic benefits resulting from reduction in load, as well as benefits to downstream users.

In North Carolina there are 630 impaired water bodies, with 111 TMDLs approved since January 1996 (NCDENR DWQ; 2003). The main impairment in North Carolina is microbial contamination, primarily fecal coliform bacteria, which has been identified in 290 water bodies and accounts for 46% of the state's total impairments (USEPA 2006). A water body is in compliance with respect to fecal coliforms, used as fecal indicator organisms for ambient water quality, when the geometric mean concentration does not exceed 200 colony forming units (cfu) per 100 mL (microfilter count) for five consecutive samples examined over a 30-day period and the concentration does not exceed 400 cfu per 100 mL in more than 20% of the samples examined during such a period (NCDENR DWQ, 2003). Almost half the water bodies in North Carolina do not meet one or both aspects of this standard, and these water bodies are considered impaired. Potential public health risks arise when there are elevated levels of fecal coliform bacteria detected in ambient waters as these may potentially indicate the presence of waterborne pathogens. This is of particular importance because many of these impaired water bodies serve as sources of drinking water and are frequently used for recreational purposes, both of which can lead to exposures to the population.

Northeast Creek, a waterbody with high levels of fecal coliform would benefit from the addition of a health risk assessment as a part of its larger watershed restoration plan to better understand how the costs of compliance can be balanced against the cost of health risks associated with non compliance. Northeast Creek is classified as an impaired water body through measured elevated levels of fecal coliform bacteria (NCDENR DWQ 2003). The Northeast Creek watershed is 47 square miles in area and flows 16 miles from its origin into Jordan Lake Reservoir. Of those 16 miles, a 9.8-mile segment is impaired by fecal coliform bacteria.

Figure 1: Northeast Creek Watershed



Both the creek and the reservoir are routinely used for recreational purposes and the Jordan Lake Reservoir also serves as a source of drinking water for the cities of Cary and Apex, as well as North Chatham County. The health risk assessment developed in this paper will enable public health officials to address both the potential health effects and the costs of elevated levels of fecal coliform bacteria levels in the water body, as well as to quantify the societal benefits associated with reductions of fecal coliform bacteria loads and hence, exposures of the general public in the Northeast Creek watershed.

BACKGROUND

Currently many of the nation's waterways still do not meet water quality standards; thus they affect many aspects of life, from the cost of water treatment (drinking water) to the availability of recreational outlets. The need to bring the nation's water into compliance is also extremely important because of its impact on public health. Various pollutants such as chemicals, metals and biological organisms contaminate recreational waters causing thousands of people to become ill each year. This costs the nation billions of dollars annually in lost revenue and medical expenses (Gaffield et al 2003, Wade et al 2006).

History has shown that noncompliance of a waterbody, especially of those with high levels of fecal coliform, can have an adverse impact on a community. Fecal coliforms are organisms that are usually present in the digestive tracts of warm-blooded animals (i.e. humans, pets, farm animals and wildlife) and are excreted in feces (USEPA 2006). Fecal coliforms are not considered hazardous themselves, but they indicate the presence of disease-causing bacteria, such as enteric pathogens associated with human waste (Griffin et al, 2001; Whitlock et al, 2002).

Recreational waters are defined as "all running or still fresh waters or parts there of, and sea water, in which bathing is explicitly authorized by the competent authorities" (Zmirous et al 2003). Waterways, such as beaches, rivers, and lakes are extremely important in the United States, and are the number one recreation spot in the country (NRDC 2006). Every year, 1.8 billion trips are made to the nation's waterways for swimming, fishing, boating, and relaxation, resulting in about six trips per person per year (NRDC 2006). Considering the frequency of use and the number of people using them, contaminated recreational waters have become a source of potentially significant environmental exposures. Over the past 15 years there has been an increase in the number of outbreaks of microbial disease due to recreational water, especially those caused by a biological contaminant such as fecal bacteria (Wade et al 2006, CDC 2006).

Table 1: Number of reported Recreational Outbreaks in the United States due to fecal contamination from 1991-2004

Year	States	Number of Outbreaks	Number of illness reported.
1991-1992	21	39	1,825
1993-1994	14	26	1,714
1995-1996	17	37	9,129
1997-1998	18	32	2,128
1999-2000	23	59	2,093
2001-2002	23	65	2,536
2003-2004	26	62	2,698

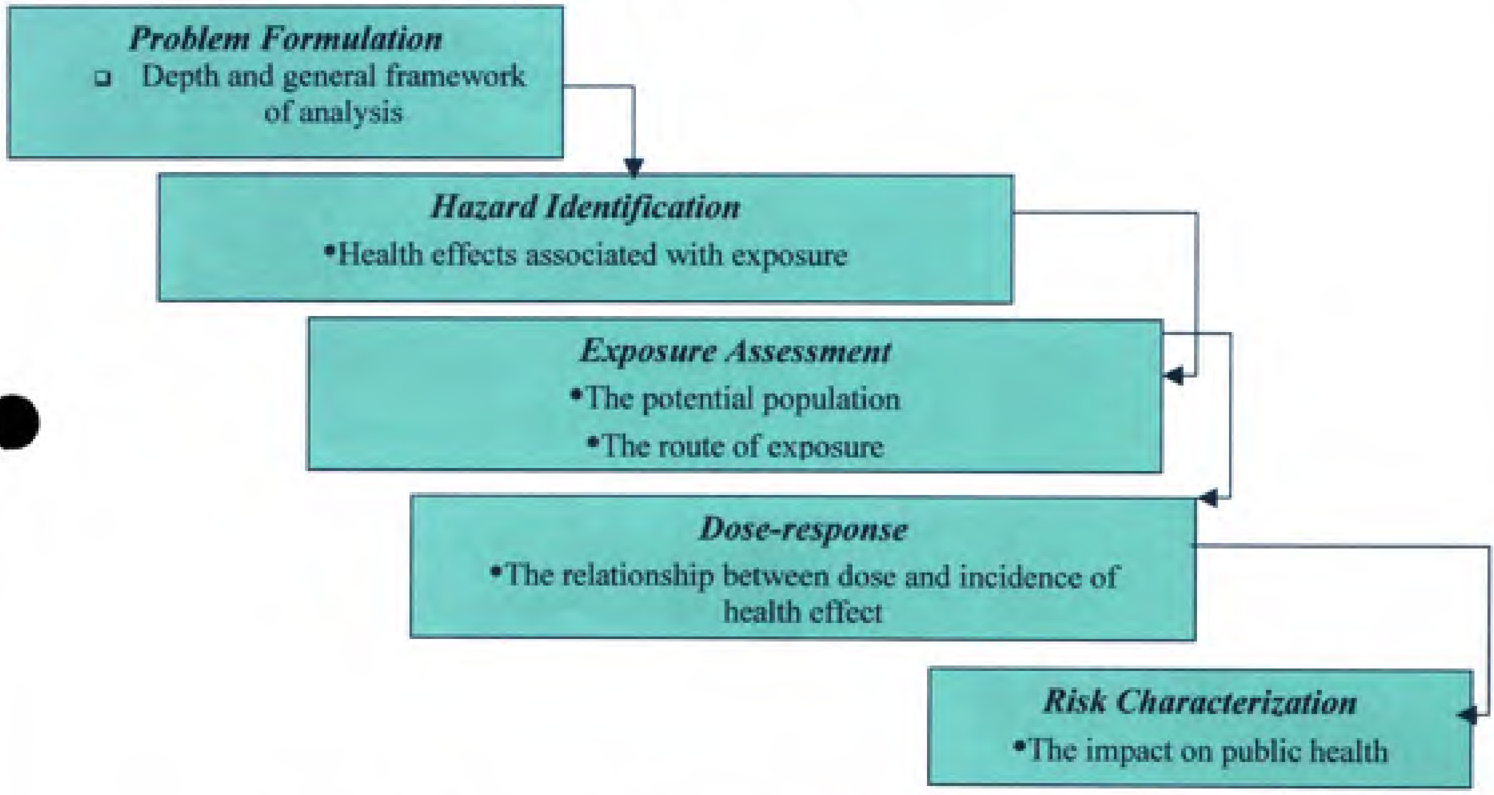
Numerous studies have shown a relationship between the microbial quality of water used in recreational activities (i.e. swimming) and the risk of health problems. Bathers exposed to high concentrations of indicator organisms showed a statistically significant increase in the risk of acquiring symptoms in relation to non-bathers (Prieto et al 1994). Typical symptoms associated with exposure to pathogens that can accompany high levels of fecal indicator bacteria are eye and ear discharge, skin rashes, gastrointestinal problems, and acute febrile respiratory illness (van Asperen et al 1998, Craig et al 2003, Gaffield et al 2003, Fleisher and Kay 2006). Literature has established that there is an increased risk of adverse health associated with swimming in recreational waters (van Asperen et al 1998, Davies et al 2000, Henrickson et al 2001, Soller et al 2003).

The impact of poor water quality goes beyond just health effects, but also has an economic cost. Its been estimated that globally polluted waters generate over 120 million excess gastrointestinal illness episodes annually, resulting in 12 billion dollars a year in health costs (Dwight et al 2005). Studies found that health costs associated with water-pollution related illnesses result in a significant financial burden to the individual and aggregate into large public health costs (Sandler et al 2002, Dwight et al 2005). Symptoms for poor water quality are more than just uncomfortable and annoying, but have real economic costs in the forms of medicines, doctors' visits, and lost income from missed workdays. By understanding all the consequences of poor water quality, it will be easier for policy makers to justify mitigation strategies. A particularly important aspect of this justification is understanding the net cost of implementing that strategy minus the savings in public health brought about by reduction in microbial exposures.

METHODS:

Risk assessment is a process of collecting, analyzing and representing scientific information to improve decision-making, accomplished through a multi-step methodology of problem formulation, hazard identification, exposure assessment, dose response, and risk characterization (USEPA 1998).

Figure 2: Framework a of Health Risk Assessment



During the problem formulation stage, stakeholders come to an agreement on the focus, scope, and parameters of the assessment. The depth of the analysis (i.e. factors to be considered or excluded and the scenarios under which risk is to be assessed) is addressed during the problem formulation phase, which serves as the general framework throughout the risk assessment. The second step is hazard identification; here the pathogens and potential populations are identified and the categories of potential health effects are assessed. The third step is exposure assessment; here the potential exposure pathways and calculation of the magnitude of exposure through each of these pathways is identified. Once hazard identification and exposure assessment are complete, it is important to determine the relationship between exposure and the probability and/or severity of any adverse effects identified in hazard identification. This relationship is referred to as exposure response or the dose-response function. Finally, the estimates of exposure under the scenarios of interest are used in the exposure-response functions to estimate the probability and/or severity of adverse effects. This risk characterization stage includes a discussion of both uncertainty in risk estimations and variation of risk between individuals. The final output of the risk assessment summarizes the likelihood and significance of adverse effects due to exposure and possible tools to minimize potential adverse health effects (USEPA 1998).

Problem Formulation:

Currently many of the nation's waterways still do not meet water quality standards, thus they affect many aspects of life, from the cost of water treatment (drinking water) to the availability of recreational outlets. The need to bring the nation's water into compliance is extremely important because of its impact on public health. Various pollutants such as chemicals, metals and biological organisms contaminate recreational waters causing thousands of people to become ill (i.e. symptomatic) each year. One such impaired waterbody is Northeast Creek in the Piedmont region of North Carolina. Currently Northeast Creek is listed as an impaired water body as a result of elevated levels of fecal coliform bacteria. Fecal coliforms are microbes indicative of fecally contaminated waters, which could potentially also contain enteric pathogens such as *Giardia*, *Shigella*, *E. coli* O15:H7, *Campylobacter* and *Cryptosporidium*. These are zoonotic microbes capable of causing illness in humans as well as animals, and have been linked to many waterborne disease outbreaks in recreational waters (Pruss 1998).

Northeast Creek flows through a developed portion of Durham County, which contains housing developments and a city park, as well as intersecting many walking and hiking trails. Northeast Creek is a tributary of the New Hope Creek arm of the B. Everett Jordan Reservoir within the Cape Fear Watershed. The creek is located in the southwest corner of Durham County, which has continuous flow into Chatham County. The total length of the Northeast Creek is 16 miles, of which a 9.8-mile segment has been identified as impaired by fecal coliform bacteria. The impaired segment is located 2.6 miles upstream of NC HWY 55 to Durham County Waste Water Treatment Plant to a point 0.5 mile downstream of Panther Creek (NCDENR DWQ 2003).

Figure 3: Impaired sections of Northeast Creek

The EPA approved a TMDL in 2002 to address the fecal coliform contamination in Northeast Creek. Restoration of Northeast Creek is extremely important because not only do the local residents use it for recreational purposes, the creek also empties into Jordan Lake, which is used for drinking water by the surrounding counties.

The high levels of fecal coliform indicate a potential public health risk, since these levels indicate the potential presence of human enteric pathogens that may cause illness in exposed populations (Dwight et al 2005). The fecal load of Northeast Creek is made up of a combination of both point and nonpoint source contamination. The one point source is the Triangle Wastewater Treatment Plant located within the impaired segment. The remainder of the load comes from nonpoint sources, which constitutes a large portion of the fecal coliform load (NCDENR DWQ 2003). One of the major contributors of nonpoint source pollution is urban stormwater runoff (Garfield et al 2003). There are numerous studies that have linked urban stormwater runoff with increased adverse health effects in exposed human populations (Davies et al 2000). To date, the TMDL framework for Northeast Creek has focused on identifying the most significant sources rather than quantifying the health risks posed by those sources. This current report, therefore, examines the health risk and associated health care costs of recreational activities in Northeast Creek at the annual concentration level, and the target (water quality compliance) concentration level of fecal coliform after mitigation. Such information is needed to better understand the costs and benefits of alternative mitigation strategies.

Hazard Identification:

Since the 1950s epidemiological studies have attempted to establish the relationship between health risk and swimming, and have produced a large body of work that links increased health risk with high levels of microbial indicator organisms (Corbett et al 1993, Kueh et al 1995, Fleisher et al 1998, Prieto et al 1998, Pruss 1998, McLellan and Salmore 2003, Turbow et al 2003). It is important to bear in mind that these risks are not produced by the fecal coliform themselves but rather by pathogens that usually coexist with fecal coliform. The microbial indicator organism concept has been the primary tool for microbial analysis for over 50 years (Griffin et al 2001). Since many disease outbreaks associated with recreational water are caused by enteric pathogens from fecal matter, fecal coliform is a widely used and accepted indicator candidate, since its presence "indicates" the potential presence of the pathogens. Fecal coliforms are facultative, anaerobic, rod-shaped, gram-negative non-sporulating bacteria found in the intestines of warm-blooded animals and humans and are shed in fecal matter (Pruss 1998, Griffin et al 2001). Fecal coliform bacteria, like other indicator organisms, are:

- Simple and inexpensive to detect
- Present when pathogens occur
- Generally found in higher numbers than pathogens
- Generally unable to grow in the environment
- More resistant to disinfection than pathogens (Griffin et al 2001)

Although indicator organisms do not cause illnesses in exposed individuals under normal conditions, they do represent a quantitative measure of overall fecal contamination (Fleisher et al 1996, Henrickson et al 2001, McLellan and Salmore 2003, Wade et al

2006). Fecal coliform bacteria fulfill their role as indicator organisms because it is easier to monitor one group of indicator organisms than to analyze for multiple enteric pathogens that may be present in the feces of infected individuals within the general population (Seyfried et al 1985, Wiedenmann 2006). Since fecal coliform bacteria do not generally cause illness, a closer look must be taken at specific pathogens that are the leading causative agents associated with recreational exposures and produce related illnesses (Medema et al 1997, McLellan and Salmore 2003), as these will be the illnesses relevant in hazard identification for fecally contaminated water bodies such as Northeast Creek. The most commonly reported and identified enteric pathogens associated with illness in recreational waters are *Cryptosporidium*, *E. coli* O157:H7, *Giardia*, *Campylobacter,* and *Shigella*. These pathogens can potentially be present in Northeast Creek due to fecal contamination, especially from nonpoint sources, and may constitute a public health risk to recreational users of this water body.

***Cryptosporidium*:**

Cryptosporidium is a single-celled, protozoan parasite that can infect the intestinal tract of exposed animals and people. The environmentally resistant (inactive) form of *Cryptosporidium,* called an oocyst, is excreted in the feces of infected humans and animals (CDC 2007). Once an animal or person is infected, the parasite replicates in the intestines and oocysts are passed in the stool. The parasite is protected by a hardy outer wall that allows it to survive outside the body for long periods of time and makes it very resistant to routinely used chlorine-based disinfectants. During the past two decades, *Cryptosporidium* has become increasingly recognized as one of the most common causes of waterborne disease within humans in the United States. The parasite may be found in drinking water and recreational water in every region of the United States and throughout the world (CDC 2007). *Cryptosporidium* can be found in soil, food, water, or on surfaces that have been contaminated with the feces of infected humans or animals. If a person ingests the parasite, they have a high likelihood of becoming infected. The infectious dose established Food and Drug Administration have the possibility of having an infection with the ingestion of less than 10 oocysts of *Cryptosporidium* (FDA 2007). A feeding study done by Dupont et al calculated a median infectious dose of 132 oocysts in healthy adults. With most human enteric pathogens, the infectious dose is host dependent (i.e. age, immune status) the same dose can have a range of symptoms from asymptomatic to severe and persistent infection that can last a few months (Jones et al 2002).

This microscopic pathogen causes a diarrheal disease called Cryptosporidiosis. The most common symptom of Cryptosporidiosis is watery diarrhea. Other symptoms include dehydration, stomach cramps, fever, nausea, and vomiting, however, some infected individuals remain asymptomatic (CDC 2007). In persons with healthy immune systems, symptoms generally last from one to two weeks. The symptoms may progress in cycles where symptoms subside for a few days, then reappear before the illness is finally cleared from the body. Although *Cryptosporidium* can infect all people (immunocompetent), some groups have a higher likelihood for developing more serious and debilitating illness. Young children, elderly, pregnant woman and those with a severely weakened immune system (immunocompromised) can experience a more serious and potentially fatal form of the disease.

Escherichia. Coli O157:H7:

Escherichia. coli O157:H7 is one of several hundred different strains of the bacterium, *Escherichia coli*. Although most strains are harmless (and can serve as indicator organisms), this strain produces a powerful toxin that can cause severe illness. *E. coli* O157:H7 can be found in the intestines of healthy animals and was first recognized as an enteric pathogen in 1982 associated with an outbreak of severe bloody diarrhea. A typical waterborne infection can result from swimming in or drinking sewage-contaminated water. Another common source of infection is through the consumption of contaminated produce (such as sprouts, lettuce, spinach), meats (salami, undercooked beef), and unpasteurized milk and fruit juices (CDC 2007).

Generally people become symptomatic from *E. coli* O157:H7 infections two to eight days (average of three to four) after being exposed to the bacteria. Typical symptoms of *Escherichia coli* O157:H7 infection include severe bloody diarrhea, diarrhea, vomiting, and abdominal cramps. Sometimes the infection causes no symptoms or a slight fever but the illness generally resolves in five to ten days. Children (especially those under five), the elderly and those with immunocompromised systems can develop a more severe illness that can result in kidney failure and even death (CDC 2007). The infectious dose for E. coli O157:H7 is quite low, anywhere between 10-100 cells; the low infectious dose is due to the fact that E. coli O157:H7 has the ability to survive the acidic conditions of the stomach (Jones et al 2002, FDA 2007).

Shigella:

Shigella belongs to a family of bacteria that can cause diarrhea in humans and that can pass from person to person. There are several different groups of *Shigella* bacteria, including *Shigella sonnei*, also known as "Group D" *Shigella*. Shigella causes an infectious disease known as Shigellosis, with Group D accounting for over two-thirds of the reported cases of shigellosis in the United States. Typical symptoms include diarrhea, fever, and stomach cramps. These symptoms usually appear a day or two after exposure to the bacterium, and the infection generally lasts from five to seven days. In some infected individuals, especially young children and the elderly, the diarrhea can be so severe that the patient requires hospitalization. A severe infection with high fever may also be associated with seizures in children less than two years old. Some infected individuals may remain asymptomatic, but will continue to pass the *Shigella* bacteria to others (CDC 2007).

Every year, about 18,000 cases of shigellosis are reported in the United States. Because many milder cases are not diagnosed or reported, the actual number of infections may be 20 times greater. Shigellosis is particularly common and causes recurrent problems in settings where hygiene is poor and the illness can sometimes sweep through entire communities. Shigellosis is more common in summer than winter (CDC 2007). *Shigella* is quite similar to *E.coli O157:H7*, in that is also has the ability to survive the acidic conditions of the stomach, giving it a low infectious dose of 10-100 cells (Jones et al 2002, FDA 2007).

Giardia:

Giardia is a single-celled, microscopic parasite, which replicates in the intestines of infected humans and warm-blooded animals and subsequently is passed in the stool. An outer shell protects the parasite so it can survive outside the body and in the environment for long periods of time. During the past two decades, *Giardia* infections have become recognized as one of the most common causes of waterborne disease (found in both drinking and recreational water) for humans in the United States. *Giardia* is cosmopolitan, being found worldwide and within every region of the United States. *Giardia* can be found in soil, food, water, or on surfaces that have been contaminated with the feces from infected humans or animals. An individual may become infected after accidentally swallowing the parasite in contaminated recreational waters. *Giardia* infections can cause a variety of symptoms, such as diarrhea, gas, stomach cramps and upset stomach. These symptoms may lead to weight loss and dehydration, but some people with Giardiasis may be asymptomatic. Symptoms of Giardiasis normally begin one to two weeks (average seven days) after becoming infected and may last two to six weeks. Occasionally, symptoms last longer in some infected individuals (CDC 2007). The median infectious dose of *Giardia* in humans is between 50-100 cysts, but some people can experience symptoms with a dose of less than 10 cysts (Finch 1996).

Campylobacter:

Campylobacter is an organism from a group of spiral-shaped bacteria capable of causing disease outbreaks in both humans and animals (zoonotic pathogen). *Campylobacter* grows best at the body temperature of a bird (lower temperature than for other warm-blooded mammals), thus allowing it to be well adapted for infection in birds, which can be asymptomatic and carry it without showing clinical symptoms. The bacterium is relatively fragile, cannot tolerate drying, and can be inactivated by prolonged exposure to oxygen. It grows only if there is less than the atmospheric amount of oxygen present. The ingestion of less than 500 cells of *Campylobacter* is sufficient enough to cause symptoms. The severity of the symptoms is not dependent on the dose but the likelihood of developing symptoms can be. *Campylobacter* causes an infectious disease known as Campylobacteriosis. Most people who become ill with Campylobacteriosis show the clinical symptoms of diarrhea, cramping, abdominal pain, and fever within two to five days after exposure to the organism. The diarrhea may be bloody and can be accompanied by nausea and vomiting. The illness typically lasts one week, however, some infected individuals can remain asymptomatic. In persons with compromised immune systems, *Campylobacter* occasionally spreads to the bloodstream and causes a serious life-threatening infection (CDC 2007).

Campylobacter is one of the most common bacterial causes of diarrheal illness in the United States; with many more cases go undiagnosed or unreported. Campylobacteriosis is estimated to affect over one million persons every year, or 0.5% of the general population. Campylobacteriosis occurs much more frequently in the summer months than in the winter and the organism is isolated from infants and young adults more frequently than from other age groups (and from males more frequently than females). Although Campylobacter doesn't commonly cause death, it has been estimated that approximately 100 persons with Campylobacter infections may die each year (CDC 2007). To determine the presence and concentration of each of these pathogens would be laborious and inefficient, so the use of fecal coliform can be a more effective way of determining the public health risk.

Exposure Pathways:

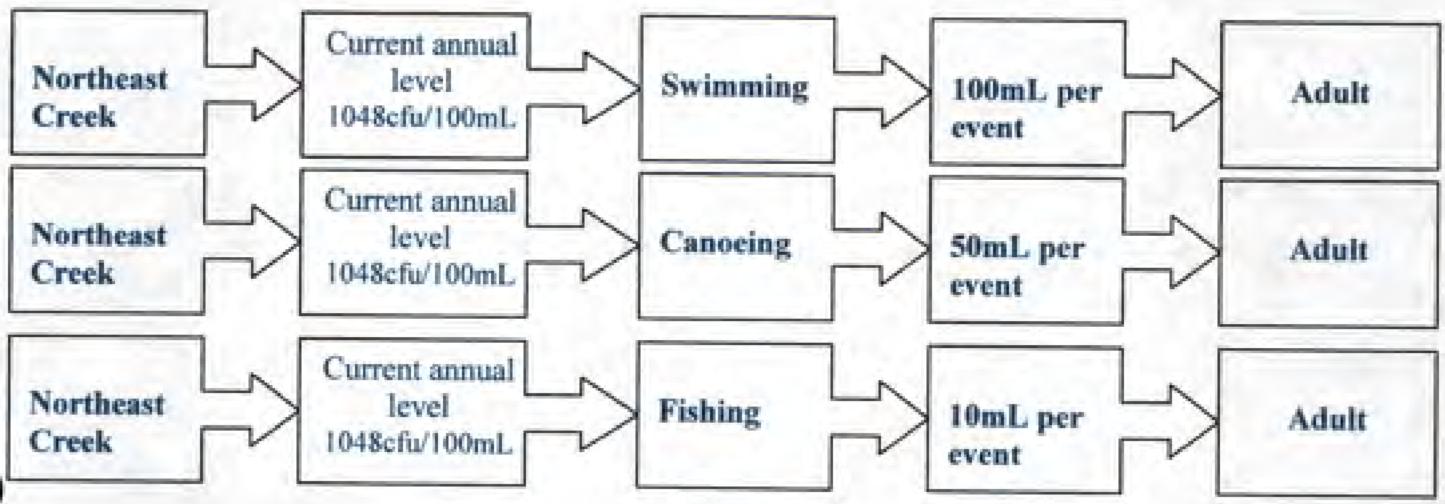
Exposure assessment is a process to determine the actual exposure to the population under the scenarios defined in the problem formulation. This includes information on the size and nature of the population exposed; the route, concentration, and distribution of the microorganisms and the duration of exposure (Haas et al 1999). The three primary exposure pathways relevant in the present study are inhalation, ingestion, and dermal absorption. For enteric pathogens, ingestion is the dominant exposure pathway, and so it is the pathway considered here. The most relevant ingestion pathway is consumption through contaminated food or water; in the current study the focus is on direct drinking of contaminated surface water or unintentional (incidental) drinking of water during recreational activity (Jones et al 2002). In recreational waters people swim, fish and participate in numerous water sports; during these activities they are exposed through incidental ingestion (Soller et al 2003, Styen et al 2003). The figure below illustrates the most common route of exposure in recreational water.

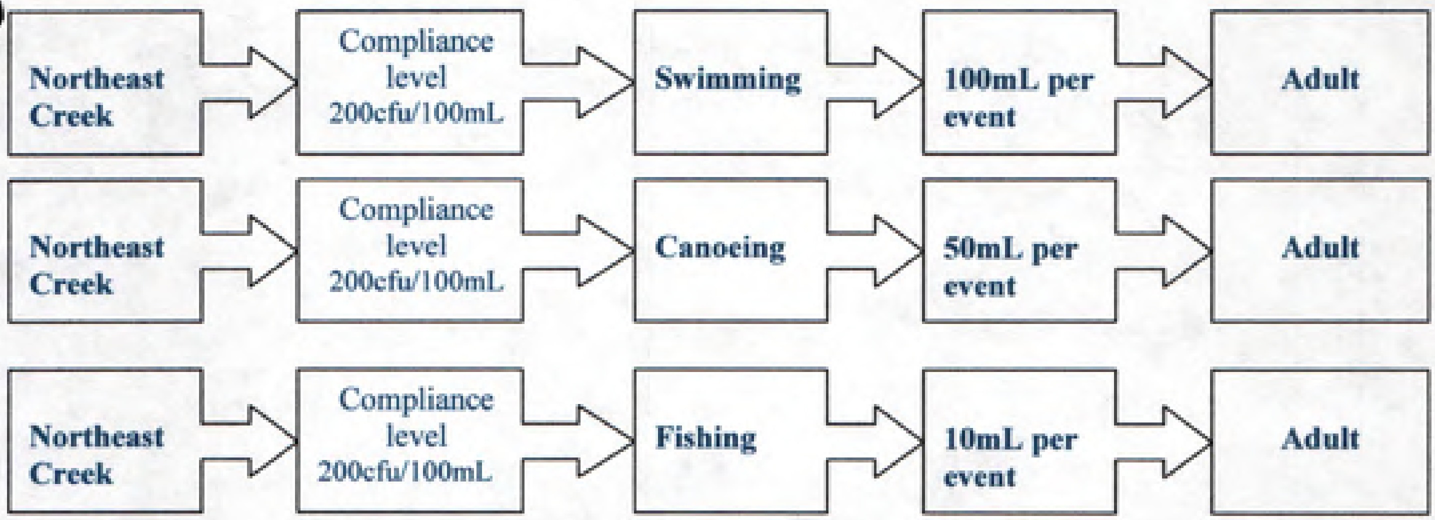
Figure 4: Typical exposure pathway for recreational water

The source box represents the environmental medium of the exposure. For exposure pathways in recreational waters, the most common environmental media are streams, lakes and rivers. The microbial concentration box represents the concentration of the water at the point of exposure. The activity box and the ingestion box are linked together; for each activity there is an activity-specific amount of water that can be potentially ingested. The EPA has established exposure factors (amount of water ingestion per contact with recreational water) that depend on the size, age, and sex of the individual (USEPA 1997).

The dominant exposure pathway in Northeast Creek is incidental ingestion of water during recreational activities. The three most common recreational activities in Northeast Creek are fishing, canoeing and swimming. With each activity there is a varying amount of water accidentally ingested. According to the Steyn et al article, during a full body contact event such as swimming, a person is likely to involuntarily ingest ~100mL per event. For intermediate contact such as canoeing, a person is likely to involuntarily ingest 50mL of water per event. For minimal contact such as fishing, a person is likely to involuntarily ingest 10mL of water per event. This report considers six main scenarios, the three recreational activities at the two different concentration levels (the existing annual average concentration and the concentration that would exist under compliance). The existing annual concentration for Northeast Creek is 1048cfu/100mL, and the creek is considered in compliance with water quality standards at concentrations of 200cfu/100mL. The figure below illustrates the six scenarios considered in this report.

Figure 5: Scenarios for Northeast Creek




Northeast Creek
Compliance level 200cfu/100mL
Swimming
100mL per event
Adult
Northeast Creek
Compliance level 200cfu/100mL
Canoeing
50mL per event
Adult
Northeast Creek
Compliance level 200cfu/100mL
Fishing
10mL per event
Adult

Dose Response:

Dose response assessment provides the link between exposure to a hazardous agent and the probability and/or the severity of ensuing health effects (Teunis and Haavelaar 2000). There is a conditional relationship between infection and illness, which can be described as

(Equation 1) $$P\,(ill/dose) = P(ill/inf) \times P(inf/dose\,).$$

The current study uses a simple "one hit" dose-response model in which each ingested microbe carries a probability of inducing illness. Under this assumption, one obtains (Teunis et al 1999):

(Equation 2) $$P_{ill} = 1\text{-}\exp^{-(\alpha * C * V\,)}$$

α = slope factor (probability of illness per ingested microbe)

C = concentration of the number of microbes ingested per 100mL

V = volume increments of 100mL of water ingested in an event (Teunis et al 1999).

The value of α in equation 2 is a function of the microorganism and the sensitivity of the individual exposed. Each microorganism has a unique value of α, even among different strains of the same organism. However the primary dose response data employed here used the concentration of fecal coliform (the indicator) as the measure of exposure rather then the concentration of specific pathogens. Therefore, equation 2 becomes:

(Equation 3): $$P_{ill} = 1\text{-}\exp^{-(\alpha_{fc} * C_{fc} * V\,)}$$

The dose-response data then provide an estimate of α_{fc}. By noting that illness is not actually caused by fecal coliform but rather by the microbes mentioned in the hazard identification, one finds:

$$(\text{Equation 4}): P_{ill} = 1\text{-exp}^{-(\alpha_{fc}*C_{fc}*V)} = P_{inf} = 1\text{-}e^{-}[(\alpha_{Cryptosporidium} * C_{Cryptosporidium}) + (\alpha_{Giardia} * C_{Giardia}) + (\alpha_{Campylobacter} * C_{Campylobacter}) + (\alpha_{Shigella} * C_{Shigella}) + (\alpha_{E.\ coli} * C_{E.\ coli}) * V]$$

Imagine further that there is a ratio $R_{Cryptosporidium} = (C_{Cryptosporidium}/C_{FC})$, $R_{Giardia} = (C_{Giardia} * C_{FC})$, $R_{EC} = (C_{E.coli\ O157:H7} / C_{FC})$, $R_{Shigella} = (C_{Shigella} / C_{FC})$, $R_{Campy} = (C_{Campylobacter} / C_{FC})$. Then equation 4 can be written:

$$(\text{Equation 5}): P_{ill} = 1\text{-exp}^{-(\alpha_{fc}*C_{fc}*V)}$$

$$= 1\text{-}e^{-}\{[(\alpha_{Cryptosporidium} * (R_{Cryptosporidium} * C_{FC})) + (\alpha_{Giardia} * (R_{Giardia} * C_{FC})) + (\alpha_{Campylobacter} * (R_{Campylobacter} * C_{FC})) + (\alpha_{Shigella} * (R_{Shigella} * C_{FC})) + (\alpha_{E.\ coli} * (R_{E.\ coli} * C_{FC}))] * V\}$$

$$= 1\text{-}e^{-}\{[(\alpha_{Cryptosporidium} * R_{Cryptosporidium}) + (\alpha_{Giardia} * R_{Giardia}) + (\alpha_{Campylobacter} * R_{Campylobacter}) + (\alpha_{Shigella} * R_{Shigella}) + (\alpha_{E.\ coli} * R_{E.\ coli})] * C_{FC} * V\}$$

From equation 5, we find that

$$(\text{Equation 6}): \alpha_{fc} = [(\alpha_{Cryptosporidium} * R_{Crypto}) + (\alpha_{Giardia} * R_{Giardia}) + (\alpha_{Campylobacter} * R_{Campylobacter}) + (\alpha_{Shigella} * R_{Shigella}) + (\alpha_{E.\ coli} * R_{E.\ coli})]$$

If an epidemiological study finds a value for α_{fc}, therefore, that same value of α_{fc}, can be applied to exposures in Northeast Creek if one assumes the various values of R are the same in Northeast Creek and the water body used in the epidemiological study.

There have been a few epidemiological studies that establish the value of α_{fc}, in recreational waters (Pruss 1998), although not directly in Northeast Creek. So in order to construct a dose response function for Northeast Creek, epidemiological studies in which similar recreational activities occurred in water bodies with elevated levels of fecal coliform must be used. Of the few epidemiological studies that looked at health effects of recreational waters, there are two particular studies that are similar in design and execution and can provide the necessary information to obtain a value for α_{fc} to be applied in Northeast Creek (again, conditional on the assumption that the R values are the same, an assumption that cannot be verified at present). The Cobert et al 1994 and Prieto et al 1998 studies are both cohort studies, meaning that the studies used a group of people with common characteristics or experience. In these cases, researchers studied beach-goers at local recreational spots (the local beaches in the respective nations). The investigators interviewed beach-goers about their health and the types of activities that they participated in at the beach that day (such as swimming, sailing, surfing etc). Following the initial interview, the subjects were interviewed again seven days later about their health (if they were infected by any enteric pathogens it would take three to four days for symptoms to become apparent). The investigators categorized the indicator concentrations and calculated a probability of effect for individuals contacting the water at each point (the number of people who experience symptoms divided by the total number of people exposed) for each category. For each study at the points of exposure a dose response model was constructed by plotting the probability of effect against the concentration of indicator organism in cfu/100mL of fecal coliform (C_{FC} in equation 6). A linear regression was performed, with the slope being the product of $\alpha_{FC} * V$ in equation 6.

Figure 6: Corbett et al Study

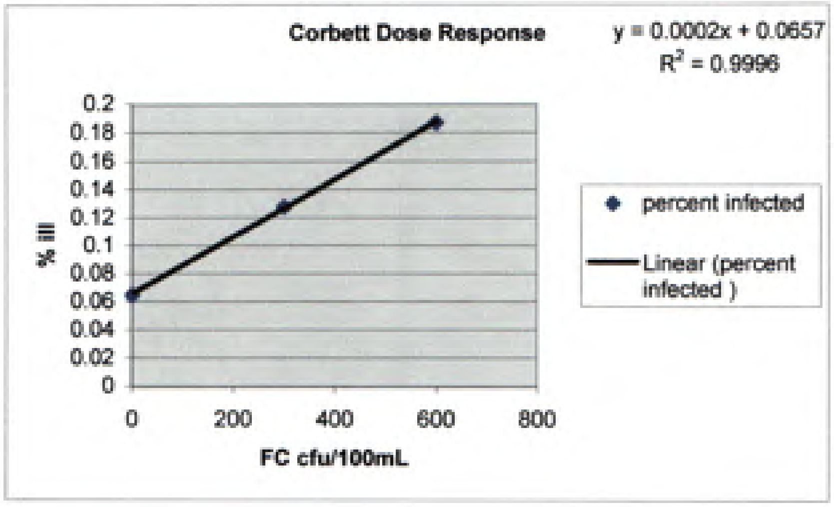
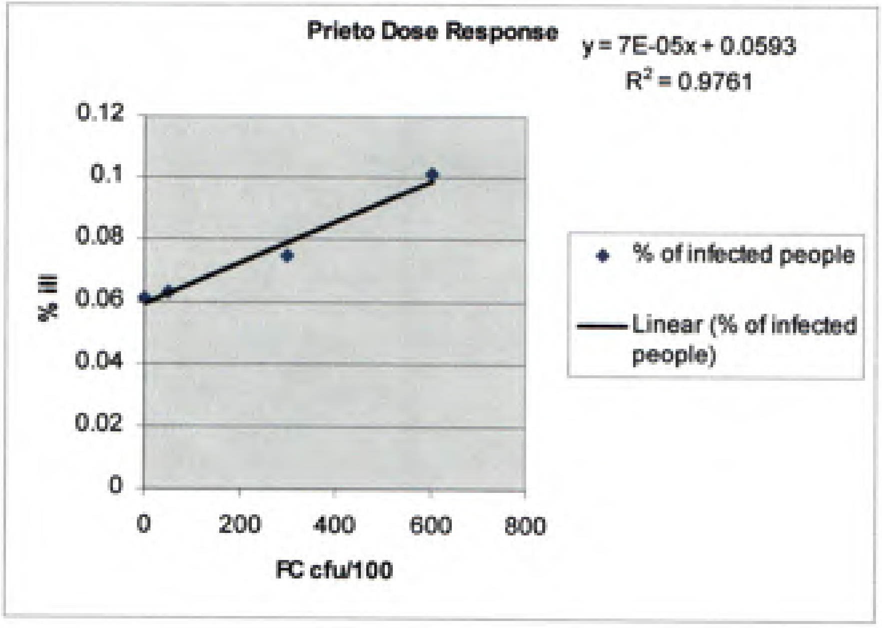


Figure 7: Prieto et al Study

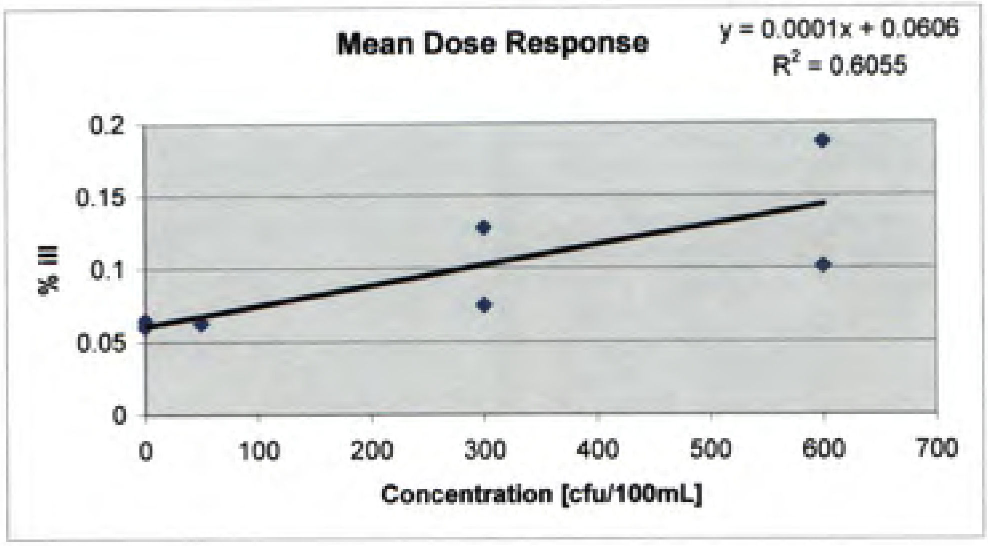


The two studies had different slopes, [Cobrett et al 1993: $y = 2E\text{-}04x + 0.0657$, $R^2 = 0.9996$ and the Prieto et al 1999: $y = 7E\text{-}05x + 0.0593$, $R^2 = 0.9761$] and a similar background probability of effect at about 6%. But both studies had only a few data points. So in order to improve the estimate of dose-response, the data sets (Table 2) were combined to create a mean dose response model. Pooling data points generally acts to increase the statistical precision of the dose response estimation (Hass et al 1999). The result is shown in figure 9.

Table 2: Data for mean dose response

Study	Conc. of Fecal coliform cfu/100mL	Probability of effect
Cobrett et al		
	0	0.065
	300	0.128
	600	0.187
Prieto et al		
	0	0.061
	50	0.063
	300	0.075
	600	0.101

Figure 8: Mean Dose Response



The linear regression of the pooled dose-response data resulted in an equation of y = 0.0001x + 0.0606 with an $R^2 = 0.6055$. Therefore, the value of α_{fc} * V for this epidemiological population is 0.0001 (units of probability of infection per cfu/100mL). It is assumed here that P(ill/inf) is equal to in equation 1 (if the value is less than 1, this is a hidden variable with the estimate of α_{fc}). Finally, note that V in equation 6 is the volume of water (in units of 100mL increments) consumed during an exposure event. In the epidemiological studies, swimming was the primary exposure pathway, so V was 1 (since the ingested volume was 100mL). If the value of α_{FC}*V is 0.0001 when V is 100mL, than α_{FC}*V will be 0.0001X when the ingestion of water is other than 100mL, and where X is the ratio of the actual water consumed in an event divided by 100mL. As a result, the final dose-response function used here is:

(Equation 7): $$P_{ill} = 1 - e^{-0.0001 * X * C_{fc}}$$

From the exposure-assesment section, note that for Northeast Creek, X is 1 for swimming (100mL/100mL), 0.5 for canoeing (50mL/100mL), and 0.1 for fishing (10mL/100mL).

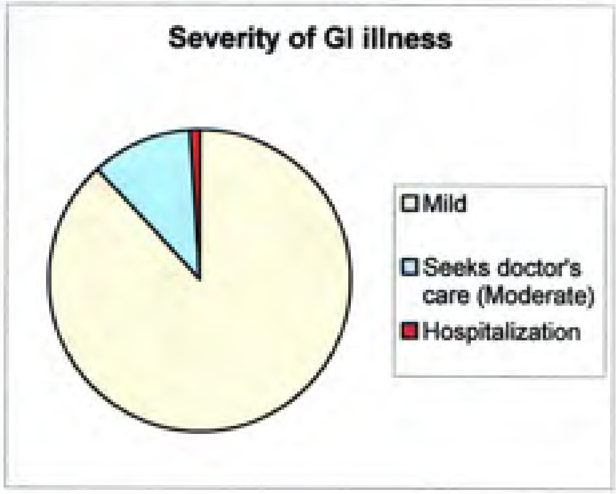
RISK CHARACTERIZATION:

The last step of a risk assessment is the risk characterization stage; at this stage an accurate characterization of the probability and/or severity of the hazard must be established (Rabinovici et al 2004). Along with addressing severity of the hazard, risk characterization also can provide information components such as the cost of remediation, prevention, and treatment. Since this study looks at the probability of illness (the presence of illness is identified by the occurrence of symptoms in this study) due to high fecal coliform load, there should be a characterization of the economic cost of health associated with this illness.

There is no one particular study that addresses the economic health cost of high fecal load; however, there have been studies done on the economic cost of gastrointestinal illness in general (Sandler et al 2002), and the economic cost of poor water quality due to particular pathogens (Corso et al 2003). Adverse health effects from poor water quality result in lost time at work, visits to the doctor, expenditures on medications, and significant nonmarket impacts that represent the willingness to pay for swimming and avoiding getting sick. Of all the various economic costs, the two main components are the direct costs (including medical care, medications, doctor visits and hospital visits) and the indirect costs (such as loss of productivity, and the loss of income due to illness) (Sandler at el 2002, Given et al 2006). Studies have found that the majority of illnesses are self-limiting and place little demand on the health care system; however there are some cases that are severe enough to require hospitalization and present a large expense to the individual and society (Dwight et al 2005). The large cryptosporidium outbreak in Milwaukee, Wisconsin in 1993 exemplified both the self-limiting nature and economic burden of an outbreak of disease from a waterborne pathogen. An estimated 403,000 residents become ill, but only a fraction (~12%) experienced a moderate to severe form of the illness requiring some form of medical attention (Corso et al 2003). In monitoring of illnesses from waterborne outbreaks, only the ones that are severe enough to require medical attention are the ones reported to local health departments. This is important to note because it shows the difficulty in determining the full impact of disease from a waterborne pathogen since the majority of the illnesses are mild and individuals do not seek treatment (AAM 2002). The results can be a significant underreporting of disease.

The range in severity of illness also makes it difficult to accurately estimate the total economic burden of symptom both on the individual and society. However, it is possible to estimate at least the direct costs of poor water quality on the individual through examination of cost studies done on outbreaks caused by waterborne pathogens. The Corso paper (Corso et al 2003) presents information on how costs can vary with severity.

Figure 9: Typical severity of GI illness



Of all people who are symptomatic 88% experience symptoms that result in a mild form of the illness, 11% experience more moderate forms of the illness that require some form of medical attention, and 1% experience symptoms that result in a severe form of the illness that requires hospitalization. These three categories of illness each have associated costs either from medical or from loss of income by staying home from work or both. Studies have estimated a cost with each category of severity (mild, moderate, severe) of illness; the estimates included costs of medical care as well as lost days of work. The cryptosporidium outbreak in Milwaukee was the largest documented outbreak caused by a waterborne pathogen in the United States in the past 25 years. The Milwaukee case showed how severity and economic burden varies among individuals in the same community. The table below describes the portion of exposed population that experienced each category of severity, cost of over the counter medications, and days home from work.

Table 3: Category of Severity (data from Milwaukee outbreak)

	Category of severity		
	Mild	Moderate	Severe
Percentage of population	88%	11%	1%
Price of OTC meds	6	6	6
Lost productivity (in days)	1.3	3.8	13.5

[Corsco et al 2003]

Using this information it is possible to construct and estimate a similar cost burden profile for Northeast Creek, based on the assumption that the distribution of cases across the categories of severity is similar for exposure in Milwaukee and Northeast Creek. The economic burden estimate for Northeast Creek is limited to only cost of over the counter medicine and loss of income due to days missed of work. The economic burden equation for Northeast Creek is:

(Equation 8): Average cost = $\{[(I*D_{mild}) + (J*D_{moderate}) + (K*D_{severe})] * M\} + O$

D_{mild} = Days of work lost with mild illness

$D_{moderate}$ = Days of work lost with moderate illness

D_{severe} = Days of work lost with severe illness

M = Income per day (USD)

O = The price of over the counter medications averaged over the 3 categories of severity.

I = Fraction of ill population with mild symptoms (0.88 from Table 3)

J = Fraction of ill population with moderate symptoms (0.11 from Table 3)

K = Fraction of ill population with severe symptoms (0.01 from Table 3)

Table 4: The cost of symptoms per illness event by severity

	Mild	Moderate	Severe
Price of OTC meds	$ 6.00	$ 6.00	$ 6.00
Lost productivity (in days)	1.30	3.80	13.50
Income per day	$180.57	$180.57	$180.57
Cost of meds and loss of work days	**$240.74**	**$692.17**	**$2,443.70**
Average cost per illness		**$312.43**	

Equation 9 estimates the average cost per illness occurring. For an individual that uses Northeast Creek the mean or expectation value of the annual economic cost of impaired water quality equals the average cost per illness ($312.43) times the probability of a illness occurring over the course of a year.

The public health risk associated with elevated levels of fecal coliform in Northeast Creek varies with the concentration of the water. The annual concentration of Northeast Creek is 1048 cfu/100mL, and the compliance concentration is 200 cfu/100mL. The table below shows the health risk and associated health costs for the six exposure scenarios.

Table 5:The probability of illness and costs for Northeast Creek

Activity	Concentration	P_{ill} per even	Cost	Annual P_{ill} (6 events per year)	Annual Cost
Swimming	1048cfu/100mL	0.10	$ 31.09	0.47	$ 145.83
Swimming	200cfu/100mL	0.02	$ 6.19	0.11	$ 35.33
Canoeing	1048cfu/100mL	0.05	$ 15.54	0.23	$ 72.92
Canoeing	200cfu/100mL	0.01	$ 3.09	0.06	$ 17.66
Fishing	1048cfu/100mL	0.01	$ 3.11	0.05	$ 14.58
Fishing	200cfu/100mL	0.00	$ 0.62	0.01	$ 3.53

The annual P_{ill} was calculated by multiplying the probability for a single event times the annual number of events (6) per year. The costs and the probability of illness remain low, but it is important to note that equation 8 is based on an adult with a healthy immune system. The rates might be expected to be higher in children, the elderly and immunocompromised individuals. It is also important to note that when a child becomes ill, their primary caregiver (most often a parent) has to stay home from work, essentially resulting in loss of productivity.

Discussion:

The disease burden in terms of individual suffering and economic cost from poor water quality is small on a per capita basis but can be substantial at the level of a full society (Fleisher et al 1998). The individual cost in Northeast Creek developed here is uncertain due to the limitations in the research design and assumptions made in the calculations. The main limitation was availability of data to establish an accurate relationship between fecal indicator concentrations and symptoms, especially for freshwater. Since there was a lack of data there were a few assumptions introduced into the calculations to determine the probability of an illness occurring and the associated costs.

The assumptions made in determining the probability of illness occurring dealt with the usage of the water body and the severity of the symptoms. The first assumption was in the occurrences and severity of the symptoms associated with waterborne pathogens. Many of the symptoms associated with enteric pathogens can often be confused with other diseases and infections, thus limiting the number reported to medical officials, this results in an underestimation of the diseases rate. Information was extrapolated from exposure patterns during large waterborne outbreaks, and applied to the occurrence of symptoms in Northeast Creek. The second assumption was in the behavioral patterns and usage of Northeast Creek. There is a data gap on usage of small freshwater creeks, requiring extrapolating information from larger nationwide studies. These assumptions were applied to the exposure assessment analysis, here in determining the types of activities and the incidental ingestion rates for Northeast Creek. A better study of actual rates of activities in Northeast Creek is needed.

Calculation of the probability of illness occurring has its own embedded assumptions that affect the accuracy of estimates of disease rates. The equation developed in this paper was calculated from studies based on exposure in saltwater. Equation 8 assumes that there is a constant ratio of fecal coliform concentration over that of an enteric pathogen; however this ratio is likely to vary according to the type of water body, in a manner that cannot be accounted for here. Also the data used in the equation were based on exposure among adults, so equation 7 does not account for the higher probability among sensitive populations, such as children and the elderly.

Along with the assumptions made in calculating the probability equation there were assumptions made in the calculation of the economic cost associated with symptoms. The main assumption is that lost productivity is estimated by daily income, and experiencing a symptom causes people to stay home and not work, thus reducing productivity. The economic calculations did not take into account that people often can go to work feeling ill and, while not being as productive, do not lose income for that day. Also none of the economic calculations considered the fact that Northeast Creek empties into Jordan Lake, which is a popular recreation spot with two million annual visitors (NC Parks and Recreation 2007). The impaired waters of Northeast Creek not only affect the people who live and use the creek but to a smaller degree also affect the people who use Jordan Lake. Jordan Lake is also a main drinking water source for many surrounding communities, thus impaired water feeding into the reservoir only creates higher costs in drinking water treatment for the surrounding communities.

Accurately predicting the occurrence of symptoms associated with poor water quality is made difficult not only by the limitations described above for this study but also by more general limitations within the field of water quality. Fecal coliforms have been widely used as indicators for fecal contamination, but they have been shown to have shorter survival times than certain pathogens and they give no indication of health risk from protozoa or viruses (Henrickson et al 2001). Recent studies have found that enterococci better correlated with GI illness in swimmers than fecal coliform, and depending on the water body composition (i.e. saltwater or freshwater), other indicators can be used to demonstrate more accurate correlation between indicator level and symptoms (Cabelli et al 1982, Wade et al 2006).

The indicator is not the only constraint in accurately predicting symptoms from poor water quality; the current methodology also serves as a limiting factor. Current water quality indicators are based on microbiological methods that involve culturing fecal indicators and counting the colony forming units. Culturing requires at least 24 hours before colonies are visible making it impossible for public health officials to act quickly and effectively to prevent unnecessary exposure (Wade et al 2006). The last main limitation behind the uncertainty in the present study is the difficulty in identifying the exact concentration during exposure. Since concentrations vary temporally and spatially it can be difficult to identify the exact concentration during exposure. The process is made even more difficult by the fact that many microbes attach to sediment particles and settle on the upper layer of the riverbed. As people participate in recreational activities, they kick up the sediment and can increase the microbe concentration of the water. Individual risk can then be increased. To improve increase the quality of the current health risk assessment, steps can be taken at the monitoring and modeling stage to more accurately determine the concentration in the water of Northeast Creek during times when specific activities take place.

Watershed restoration is important, but strategies and policies that try to accomplish goals can be costly and difficult to accomplish for small communities. With any decision making process it is important to identify all of the costs and benefits. Many water bodies in United States are impaired and the goal is to bring them into compliance with various reduction strategies and policies. The Clean Water Act exemplifies the United States government and its citizens' commitment to clean water. The TMDL process is helping reduce the number of impaired water bodies in the United States but its use in watershed restoration policy selection is limited. The fact still remains that poor water quality costs the nation billions of dollars (Gaffield et al 2003, Wade et al 2006). Much of this imposing cost of pollution reduction plans is because the complete cost of poor water quality is not realized. The inclusion of a health risk component in a watershed restoration plan can provide the necessary information for policy makers, allowing them to choose the most effective strategies to reach compliance.

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