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Distribution and Fate of *Escherichia coli* in Lake Michigan Following Contamination with Urban Stormwater and Combined Sewer Overflows

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ABSTRACT. Escherichia coli *distribution and persistence in nearshore Lake Michigan were assessed following heavy rains and sanitary sewer overflow (SSO) and combined sewer overflow (CSO) events over a 5-year period, including an 18-day period following 25.4 cm of rainfall in which intensive studies were conducted following multiple CSO and SSO events.* E. coli *levels in the Milwaukee estuary and harbor following SSO and CSO events ranged from 10^4 to nearly 10^5 CFU/100 mL, which were significantly higher ($p \le 0.05$) than levels following rainfall alone. Sites outside of the breakwall but within the contamination plume (e.g., within 2 km of the harbor) were an order of magnitude lower. Locations 2–5 km from the harbor ranged from below detection limits, of < 1 to 5 CFU/100 mL.* E. coli *levels corrected for dilution based on specific conductivity measurements were lower than what would be expected for loss due to dilution alone, suggesting a combination of die-off and dilution, were responsible for the rapid disappearance of these organisms outside of the harbor.* E. coli *and fecal coliforms measured concurrently demonstrated that fecal coliforms could be recovered longer than* E. coli *in the open waters of the lake.* E. coli *isolated directly from sewage treatment plant influent were found to have a marked increase in antibiotic resistance traits for ten antibiotics commonly used in the human population compared with isolates from two animal sources of fecal pollution. However,* E. coli *obtained from sewage impacted water (n = 2,513) and from stormwater impacted water (n = 1,465) collected the previous year when there were no sewage overflows, were found to have no significant difference ($p < 0.05$) in the frequency of resistance when comparing the two conditions.* E. coli *survival characteristics and population dynamics are most likely influenced by multiple factors in complex systems such as the watershed/estuarine/lake environments of the Great Lakes.*

INDEX WORDS: E. coli, *sewage overflows, antibiotic resistance, fecal coliforms, Lake Michigan.*

INTRODUCTION

Urban stormwater and sewage overflows introduce large amounts of contaminants into the Great Lakes each year and are considered major sources of water body impairment in the U.S. (Marsalek and Rochfort 2004, USEPA 2004). Urban stormwater contains metals, pesticides, pathogens, and fecal indicator bacteria and has been linked to adverse public health effects (Bannerman *et al*. 1993, Gaffield *et al.* 2003, Haile *et al.* 1999). In most municipal areas, urban stormwater is conveyed in separated sewer systems and discharged directly to receiving waters with no treatment. However, older sections of many cities around the Great Lakes are serviced by combined sewers, which are designed to capture both sanitary sewage and stormwater for conveyance to a wastewater treatment plant. While this configuration minimizes stormwater impacts on receiving waters during most rain events, the large volumes of stormwater generated during heavy precipitation can exceed the system's capacity, resulting in both stormwater and sanitary sewage being released as part of a combined sewer overflow (CSO). Separated sanitary sewers also may be overwhelmed if infiltrated with large volumes of rainwater or if a mechanical failure occurs, resulting in a sanitary sewer overflow (SSO).

In the US, it is estimated that over 770 communi-

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ties and 40 million people are serviced by combined sewer systems (http://cfpub.epa.gov/npdes/). Approximately 150 of these communities are within the Great Lakes drainage basin. In the Great Lakes states, major cities with combined sewer systems include Toledo, Buffalo, Cleveland, Detroit, metropolitan Chicago, and Milwaukee. The majority of these cities discharge sewage into the Great Lakes. One exception is certain areas within the city of Chicago that discharge into the Chicago Sanitary Ship Canal, and eventually into the Mississippi River.

CSOs and SSOs are considered the primary sources of human fecal pollution in surface water systems. The EPA estimates that roughly 3.2 trillion L of CSO wastewater is discharged annually into our nation's surface waters (USEPA 2004). Although these events occur intermittently, they do present a public health risk because they have the potential of carrying disease-causing organisms including enteroviruses, noroviruses, Coxsakie A and B, Hepatitis A, *Shigella* spp., *Cryptosporidium parvum*, and *Giardia lambia*. While there is evidence that urban stormwater, generally comprised of fecal pollution from non-human sources, also carries pathogens (Gaffield *et al.* 2003), the severity of this risk relative to sewage is unknown. Few assessment tools exist that allow for direct measure of pathogens associated with urban stormwater and sewage overflows. Rather, fecal pollution is detected by using indicator bacteria, such as *Escherichia coli* (*E. coli*), or enterococci, which are present in large numbers in the gastrointestinal tract of almost all warm-blooded animals (USEPA 2000).

Sewage overflows, urban stormwater, and in some cases upstream agricultural runoff, all contribute high levels of fecal indicator organisms to Great Lakes surface waters, and detection of these organisms by standard microbiological measures offers no information as to the source of pollution. Recent research has focused efforts towards microbial source tracking methods to differentiate between types of fecal contamination so that water pollution abatement efforts are allocated accordingly (Scott *et al.* 2002, Simpson *et al.* 2002).

These approaches are varied and can provide different levels of discrimination; however, all the approaches have inherent limitations (Field *et al.* 2003, Stewart *et al.* 2003). Antibiotic resistance testing may be useful because it is based on the well-supported hypothesis that humans and certain agricultural animals that are exposed to antibiotics will harbor antibiotic resistant bacteria in their gastrointestinal tract more frequently than hosts not exposed to antibiotics (Austin *et al.* 1997, Levy *et al.* 1988, Salyers *et al.* 2004, van den Bogaard and Stobberingh 2000). Results from previous studies have demonstrated that there is an increased proportion of fecal indicator bacteria with antibiotic resistance traits associated with human sources of fecal pollution (Guan *et al.* 2002, Hagedorn *et al.* 1999, Harwood *et al.* 2000, Parveen *et al.* 1997). This approach may not be capable of discerning specific host sources, but might be useful as an approximation of the major sources either hosts that are influenced by exposure to antibiotics or hosts, such as wildlife, that are not.

The survival and persistence of biological contaminants released into the Great Lakes is dependent on many factors. Survival rates of *E. coli* were found to be a function of water temperature, nutrient status, and competition for nutrients by indigenous microflora (Lim and Flint 1989). Water quality parameters such as high nutrient levels and turbidity have been reported to greatly prolong survival (Pommepuy *et al.* 1992). In this study, *E. coli* distribution and persistence in nearshore Lake Michigan was assessed during "worst case scenario," heavy rains in the Milwaukee River basin accompanied by CSO and SSO events. Storm events and sewer overflows occurring over a 5-year period between 2001 and 2005 were sampled, including an 18-day period in May of 2004 where precipitation averaged 22.8 cm of rain across the Milwaukee River basin. During the 5-year period, there were nine CSO events, with three occurring during May 2004 storms; seven of the nine events were sampled. SSO events also occurred during the same time in upstream areas outside of the combined sewer system. The May 2004 sewer overflows were of the largest magnitude, with an estimated 5.94 million L of rain and wastewater into local surface waters as stormwater volumes exceeded the existing capacity of sewer and wastewater treatment systems. In addition, antibiotic resistance testing was used to evaluate the resistance patterns of *E. coli* during reported sewage overflows. These patterns were compared to that of *E. coli* collected under the same conditions (post-rain) when there were no overflows to determine if there were differences in the patterns that could serve as a benchmark of the expected increase in antibiotic resistance frequency when sewage was present. This study describes the sources and fate of