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Estimated human health risks from recreational exposures to stormwater runoff containing animal faecal material

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ABSTRACT

Scientific evidence supporting recreational water quality benchmarks primarily stems from epidemiological studies conducted at beaches impacted by human fecal sources. Epidemiological studies conducted at locations impacted by non-human faecal sources have provided ambiguous and inconsistent estimates of risk. Quantitative Microbial Risk Assessment (QMRA) is another tool to evaluate potential human health risks from recreational exposures to non-human faecal contamination. The potential risk differential between human and selected non-human faecal sources has been characterized previously for direct deposition of animal feces to water. In this evaluation, we examine the human illness potential from a recreational exposure to freshwater impacted by rainfall-induced runoff containing agricultural animal faecal material. Risks associated with these sources would be at least an order of magnitude lower than the benchmark level of public health protection associated with current US recreational water quality criteria, which are based on contamination from human sewage sources.

1. Introduction

Epidemiology studies have linked swimming-associated illnesses with faecal indicator bacteria (FIB) densities in sewage-impacted recreational waters (Prüss, 1998; Wade et al., 2003; Zmirou et al., 2003). In those epidemiology studies, elevated FIB levels represent the potential presence of human faecal contamination (NRC, 2004). Although several epidemiology studies have considered non-point sources of contamination, FIB densities do not consistently correspond to risks in waters that are impacted predominantly by non-human sources, such as agricultural animals (Calderon et al., 1991; Colford et al., 2007, 2012; McBride et al., 1998). Human health effects associated with animal-impacted waters may differ from those associated with human sewage-impacted waters because the mix and densities of FIB and pathogens in animal manure are different from those in municipal wastewater. In particular, human enteric viruses are thought to be a major cause of recreator illness in human impacted waters (Sinclair et al., 2009; Soller et al., 2010a) and these gastrointestinal viruses are rarely zoonotic (Midgley et al., 2012; Oliver et al., 2003; Tei et al., 2003). Moreover, pathogen loading to recreational water from animal manure is often event-driven (e.g. rainfall), whereas wastewater outfall loading is relatively continuous, with increases of untreated or poorly treated sewage during rain events. Because of these issues, it is technically and logistically difficult to conduct epidemiology studies on predominately agricultural animal-impacted sites.

Quantitative microbial risk assessment (QMRA) is emerging as a complement to epidemiology for understanding risks in recreational waters, developing recreational water standards, and making beach management decisions. To encourage its application and use for public health protection efforts, we conducted a series of QMRA-based studies and developed an approach to compare the potential health risks associated with various faecal contamination sources in recreational waters (Ashbolt et al., 2010; Schoen and Ashbolt, 2010). To more comprehensively understand the risks associated

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with human impacted waters, we evaluated the reported results from the 2003–2004 Great Lakes epidemiologic studies (Wade et al., 2006, 2008) and showed that human enteric viruses were the likely aetiologic agents of primary concern and that using *Norovirus* as a reference pathogen accounted for the vast majority of the estimated gastrointestinal (GI) illness risk (Soller et al., 2010a). We then evaluated the implications of mixtures of human sources impacting a recreational waterbody. Our results illustrate that the source contributing the majority of risk in a waterbody impacted by a mixture of sources may not be the source that contributes the majority of the FIB when the FIB are enumerated by a culture-based method (Schoen et al., 2011). We also investigated whether the relative risks from exposure to recreational waters impacted by direct contamination from gull, chicken, pig, and/or cattle excreta were substantially different than those associated with human-impacted waters. Waters containing seagull excreta and primary sewage effluent were compared at the same FIB density. The result was a lower predicted illness risk from largely seagull-impacted waters (Schoen and Ashbolt, 2010). The results from agricultural-animal impacted-waters indicate that GI illness risks associated with exposure to recreational waters directly impacted by fresh cattle faeces may not be substantially different from waters impacted by human sources, but the risks associated with exposure to recreational waters impacted by fresh chicken, or pig faecal material appear substantially lower than waters impacted by human sources at the FIB water quality limit (Soller et al., 2010b).

Whereas our previous analyses assumed fresh faecal material was deposited directly into recreational water (Soller et al., 2010b), this study considers indirect contamination in which FIB and pathogens from manure-applied land are mobilised into surface water via a rainfall event. Application of animal manure on land is a common practice in the United States and many other countries. Modelling of runoff and stormwater contamination is a well-documented research activity (e.g., (Bhattarai et al., 2011; Burian et al., 2001; Kara et al., 2012; Liu, 1994; López-Vicente et al., 2014; Luna et al., 2006; May and Sivakumar, 2009; Vezzaro and Mikkelsen, 2012; Vezzaro et al., 2014; Whelan et al., 2014)) Prior studies of pathogen and indicator mobilisation via overland flow from land applied manures have explored the influence that numerous factors have on mobilisation (Cardoso et al., 2012; Ferguson et al., 2007; Muirhead et al., 2006; Stout et al., 2005). Those factors include manure type and method of land application (e.g., Hodgson et al., 2009; Miller and Beasley, 2008; Ramirez et al., 2009; Saini et al., 2003; Thurston-Enriquez et al., 2005), slope and ground cover (e.g., Cardoso et al., 2012; Davies et al., 2004; Ferguson et al., 2007; Hodgson et al., 2009; Miller and Beasley, 2008; Stout et al., 2005; Thurston-Enriquez et al., 2005; Trask et al., 2004; Winkworth et al., 2008; Yeghiazarian et al., 2004), rainfall intensity and antecedent soil moisture (Bradford and Schijven, 2002; Davies et al., 2004; Ramirez et al., 2009; Saini et al., 2003; Schijven et al., 2004; Sistani et al., 2009; Yeghiazarian et al., 2004), and chemical properties (e.g., Bradford and Schijven, 2002; Davies et al., 2004). Not surprisingly, mobilisation fractions (i.e., proportion of organisms in land-applied manures that are mobilised during a rain event) reported in the literature vary widely (Hodgson et al., 2009; Stout et al., 2005; Trask et al., 2004). Hence, rather than exploring all the conditions and factors described above, we conducted a series of pilot-scale experiments to characterize mobilisation of indicator organism and zoonotic pathogens from an intense rainfall event for one pasture condition.

Runoff of microorganisms from land is the net effect of multiple hydrologic processes. During our simulated rain events, some microorganisms in land-applied wastes were mobilised and transported in overland flow, while others could have been transported in the vadose zone, infiltrated into the groundwater or were retained in the manure matrix. Among the microorganisms that did mobilise and were transported, some were probably retained on plants or soil surfaces. During these transport processes, microorganisms in land-applied wastes, on soils or in runoff die or may experience regrowth, with the time for a 90% reduction in microorganism density varying widely among microbial groups and for microorganisms in different matrices. In our fate and transport model, die-off and regrowth of pathogens and indicators were not considered because the mobilisation fractions used in this study were based on data from the plots for which rainfall simulation began immediately following manure application.

2. Methods

We use QMRA to investigate potential impacts from indirect contamination of recreational water by livestock wastes. First, a "forward" QMRA was used to estimate risk associated with recreational exposure in undiluted runoff from freshly-applied livestock wastes. The forward QMRA is the familiar application of QMRA in which pathogen exposure is estimated based on source pathogen density and a fate and transport model (in this case including a mobilisation component) and risk is estimated using estimated pathogen doses and vetted dose–response models. Second, a "relative risk" QMRA model was used to compare risks from exposure to livestock-impacted waters to those associated with human sources (Schoen and Ashbolt, 2010; Soller et al., 2010b). In the relative risk model, each faecal source is assumed to contribute enough contamination such that the hypothetical waterbody contains FIB equal to a predetermined reference density, although the corresponding pathogen densities are proportional to the faecal source ratios. EPA's 2012 Recreational Water Quality Criteria values have an associated health goal with a defined illness rate (U.S. EPA, 2012a). By setting that reference density equal to EPA's recommended recreational water quality criteria in the United States, it was possible to compare the risks associated with animal-based contamination to human-based contamination. In this way we use the QMRA results to draw inferences about potential risks associated with recreation in water impacted by land-applied livestock wastes.

2.1. Exposure pathway

Fig. 1 illustrates conceptually the processes leading to human exposure to pathogens in freshwater impacted by faecal contamination from agricultural sources. We conducted a literature review to characterize the parameters associated with these processes (U.S. EPA, 2010).

2.2. Environmental monitoring

We conducted an environmental monitoring and sampling study to characterize zoonotic enteric pathogens and FIB densities in surface water affected by agricultural activities (U.S. EPA, 2010). The monitoring regime/approach included rain simulation experiments in small plots amended with cattle manure, pig slurry from a lagoon, and un-composited litter from a chicken operation (U.S. EPA, 2010). These matrices were selected because higher pathogen densities are associated with fresh faecal material, and pathogen removal efficiencies vary both between and within treatment processes (Bicudo and Goyal, 2003; Goss and Richards, 2008; Heinonen-Tanski et al., 2006; Larney and Hao, 2007; Letourneau et al., 2010; Martens and Böhm, 2009; Peu et al., 2006; Topp et al., 2009; Vanotti et al., 2005; Vinnerås, 2007; Wong and