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Human health risk implications of multiple sources of faecal indicator bacteria in a recreational waterbody☆

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ABSTRACT

We simulate the influence of multiple sources of enterococci (ENT) as faecal indicator bacteria (FIB) in recreational water bodies on potential human health risk by considering waters impacted by human and animal sources, human and non-pathogenic sources, and animal and non-pathogenic sources. We illustrate that risks vary with the proportion of culturable ENT in water bodies derived from these sources and estimate corresponding ENT densities that yield the same level of health protection that the recreational water quality criteria in the United States seeks (benchmark risk). The benchmark risk is based on epidemiological studies conducted in water bodies predominantly impacted by human faecal sources. The key result is that the risks from mixed sources are driven predominantly by the proportion of the contamination source with the greatest ability to cause human infection (potency), not necessarily the greatest source(s) of FIB. Predicted risks from exposures to mixtures comprised of approximately 30% ENT from human sources were up to 50% lower than the risks expected from purely human sources when contamination is recent and ENT levels are at the current water quality criteria levels (35 CFU 100 mL^{-1}). For human/non-pathogenic, human/gull, human/pig, and human/chicken faecal mixtures with relatively low human contribution, the predicted culturable enterococci densities that correspond to the benchmark risk are substantially greater than

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the current water quality criteria values. These findings are important because they highlight the potential applicability of site specific water quality criteria for waters that are predominantly un-impacted by human sources.

1. Introduction

Epidemiological studies link swimming-associated illnesses with levels of faecal indicator bacteria (FIB) in wastewater-impacted recreational waters (Cabelli et al., 1982; Dufour, 1984; Fleisher et al., 1996; Kay et al., 1994; Prüss, 1998; Wade et al., 2003, 2006, 2008, 2010; Zmirou et al., 2003). At a given level of FIB, risks in waters impacted by animal faeces may differ from wastewater-impacted waters because the mix and densities of pathogens in animal faeces are different from those present in municipal wastewater. In wastewater-impacted recreational waters, human enteric viruses are thought to be a major cause of illness (Cabelli et al., 1982; Sinclair et al., 2009; Soller et al., 2010a). These human viruses are generally less likely to occur in animal faeces (Feachem et al., 1983; Halaihel et al., 2010), although pigs and birds may periodically carry zoonotic waterborne viruses (Meng, 2011; Raoult, 2011). Moreover, pathogen loading to recreational water from animal faeces is often event-driven (i.e. rainfall), non-continuous, or spatially variable; whereas, wastewater flows are typically relatively continuous (Metcalf and Eddy, 2003). For these reasons, conducting epidemiological studies at predominantly non-human impacted sites can be technically and logistically challenging. Moreover, epidemiological studies at sites considered to be impacted by non-human fecal sources report potentially ambiguous results with respect to the relationship between illness and water quality (Calderon et al., 1991; Cheung et al., 1990; Colford et al., 2007, 2012; Dufour et al., 2012; McBride et al., 1998), and thus, can raise concerns over the potential applicability of epidemiology results from human impacted sites to recreational waters that are impacted by non-human faecal sources.

An increasingly popular approach to aid in the understanding of risks associated with exposures to recreational waters is quantitative microbial risk assessment (QMRA). QMRA has been used in a number of studies to examine the effects of exposures to both human and animal faecal contamination on human health (Ashbolt et al., 2010; Schoen and Ashbolt, 2010; Schoen et al., 2011; Soller et al., 2010a, 2010b; U.S. EPA, 2010). Soller et al. (2010a) evaluated results from recreational water epidemiological studies conducted in the Great Lakes, USA (Wade et al., 2006, 2008) using QMRA and concluded that human enteric viruses, and in particular viruses with similar infectivity and incubation period to norovirus, were the likely etiologic agents of the observed recreational waterborne illness. QMRA also has been used to evaluate risks associated with exposure to surface waters impacted by animal faeces. For gastrointestinal illness (GI) risks from exposure to marine waters containing seagull excreta, QMRA modelling indicates that seagull-impacted surface waters may give rise to approximately two orders of magnitude less GI risk than the level that corresponds to U.S. Environmental Protection Agency's (U.S. EPA) water quality criteria (hereafter referred to as U.S. EPA's benchmark risk) (Schoen and Ashbolt, 2010). Risks from exposures to recreational waters with direct faecal contamination (i.e., direct deposition into water where recreation is concurrently occurring) from seagulls, chicken, pigs, or cattle were predicted and compared to risks from exposures to sewage-impacted waters (Soller et al., 2010b). These results indicate that risks associated with exposure to recreational waters containing fresh cattle faeces may not be substantially different from risks associated with exposures to waters impacted by human faecal sources; whereas, the risks associated with exposure to recreational waters impacted by fresh gull, chicken, or pig faeces appear substantially lower than waters impacted by human faecal sources (Soller et al., 2010b). An additional QMRA study examined how risks from exposure to surface waters containing pathogens from land-applied (indirect) cattle, poultry, and pig manure compared to risks associated with exposures to human wastewater. The study considered differential mobilization of indicator bacteria and pathogens from manure during rainfall as well as the aging of the faeces that is standard in agronomic applications (U.S. EPA, 2010). Those results indicated that the predicted median risk of illness in water bodies that contain FIB at levels equal to the current recreational water quality criteria from land-applied manure would be at least an order of magnitude lower than the risk associated with wastewater-impacted waters. In addition, the indirect cattle contamination scenario (U.S. EPA, 2010) resulted in lower estimated relative risk estimates compared to the direct cattle contamination scenario (Soller et al., 2010b).

The above studies examined risk in idealized settings where faecal contamination was assumed to be recent and from a single source. In reality, pathogen loading to surface waters from animal faeces is complex and is influenced by the prevalence of infected animals in a watershed; the abundance of zoonotic pathogens in fresh faeces; time between defecation and rain-induced mobilization; and the path by which pathogens reach receiving water (during transport to receiving water, pathogens may be inactivated or removed via biophysical barriers) (U.S. EPA, 2009). This present work is unique in that it specifically simulates risk in waters impacted by mixed sources of enterococci. The goals were to 1) estimate human health risks from recreational exposure to waters impacted by various mixtures of faecal contamination (as represented by ENT) from diverse sources including sewage, animal sources and sources that contribute ENT but not pathogens (non-pathogenic sources), and 2) derive ENT levels that correspond to a specific illness benchmark for human and animal contamination mixtures. Health risks are