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Using *Campylobacter* spp. and *Escherichia coli* data and Bayesian microbial risk assessment to examine public health risks in agricultural watersheds under tile drainage management

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ABSTRACT

Human campylobacteriosis is the leading bacterial gastrointestinal illness in Canada; environmental transmission has been implicated in addition to transmission via consumption of contaminated food. Information about *Campylobacter* spp. occurrence at the watershed scale will enhance our understanding of the associated public health risks and the efficacy of source water protection strategies. The overriding purpose of this study is to provide a quantitative framework to assess and compare the relative public health significance of watershed microbial water quality associated with agricultural BMPs. A microbial monitoring program was expanded from fecal indicator analyses and *Campylobacter* spp. presence/absence tests to the development of a novel, 11-tube most probable number (MPN) method that targeted *Campylobacter jejuni*, *Campylobacter coli*, and *Campylobacter lari*. These three types of data were used to make inferences about theoretical risks in a watershed in which controlled tile drainage is widely practiced, an adjacent watershed with conventional (uncontrolled) tile drainage, and reference sites elsewhere in the same river basin. *E. coli* concentrations (MPN and plate count) in the controlled tile drainage watershed were statistically higher (2008–11), relative to the uncontrolled tile drainage watershed, but yearly variation was high as well. *Escherichia coli* loading for years 2008–11 combined were statistically higher in the controlled watershed, relative to the uncontrolled tile drainage watershed, but *Campylobacter* spp. loads for 2010–11 were generally higher for the uncontrolled tile drainage watershed (but not statistically significant). Using MPN data and a Bayesian modelling approach, higher mean *Campylobacter* spp. concentrations were found in the controlled tile drainage watershed relative to the uncontrolled tile drainage watershed (2010, 2011). A second-order quantitative microbial risk assessment (QMRA) was used, in a relative way, to identify differences in mean *Campylobacter* spp. infection risks among monitoring sites for a hypothetical exposure scenario. Greater relative mean risks were obtained for sites in the controlled tile drainage watershed than in the uncontrolled

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tile drainage watershed in each year of monitoring with pair-wise posterior probabilities exceeding 0.699, and the lowest relative mean risks were found at a downstream drinking water intake reference site. The second-order modelling approach was used to partition sources of uncertainty, which revealed that an adequate representation of the temporal variation in *Campylobacter* spp. concentrations for risk assessment was achieved with as few as 10 MPN data per site. This study demonstrates for the first time how QMRA can be implemented to evaluate, in a relative sense, the public health implications of controlled tile drainage on watershed-scale water quality.

1. Introduction

Human campylobacteriosis is the leading bacterial gastrointestinal illness in Canada (Galanis, 2007), with a reported incidence rate of ~25 cases per 100,000 people per year across Canada in 2009 (Government of Canada, 2012). The health burden is much larger because *Campylobacter* spp. illnesses are always under-reported (Thomas et al., 2008). The species responsible for campylobacteriosis are not always known because positive human stool samples are not consistently sub-typed (*i.e.*, identified as *Campylobacter jejuni*, *Campylobacter coli*, *Campylobacter lari*, *etc*). While food consumption (especially poultry) is considered to be the primary transmission route (Doorduyn et al., 2010), environmental transmission from bovine and other sources is also implicated (O'Connor, 2002; Till and McBride, 2004; Gabriel et al., 2010).

The presence of pathogens and associated fecal indicator bacteria in surface waters has become an important consideration for source water protection in Canada (Hrudey and Hrudey, 2004). Land where manure/biosolids are applied, grazing areas, manure storage areas, wastewater effluents, septic systems, and wildlife are among the many sources of fecal pollution in watersheds. Environmental monitoring programs are used to investigate fecal indicator bacteria and pathogen levels in surface waters and their trends over time and space. These efforts help to identify potential pollution sources and drivers and inform the development of prudent risk assessment and source water protection strategies, particularly when information about watershed scale occurrence of pathogens like *Campylobacter* spp. are available.

Various management practices implemented at the farm level can influence the transport of chemicals and microorganisms of concern to a receiving body of water. Artificial subsurface drainage (tile drainage) is used in many parts of the world to drain excess water from land to promote crop growth. However, tile drains are also pathways by which field contaminants can rapidly enter adjacent surface water systems (Lapen et al., 2008). Controlled tile drainage practices can contribute to a reduction of overall pollution loading from tile-drained fields during certain times of the year. Controlled tile drainage, a form of tile drainage management where tile flow is restricted, is considered a beneficial management practice (BMP) for nutrient and water conservation purposes to boost crop yields (Cicek et al., 2010) and for reducing pollution of surface water bodies that receive tile drainage (Drury et al., 1996). This BMP was found, via modelling, to significantly reduce nitrogen water pollution in direct runoff at the river basin scale in Canada (Que, 2011), and it has been considered a potentially important BMP in alleviating mega-scale agricultural nutrient water pollution problems in the United States (Nistor and Lowenberg-DeBoer, 2007). Nevertheless, since conventional agricultural practices such as fertilizing crops with organic fertilizers like manure and biosolids can be a source of fecal pollution to tile drains and ultimately to adjacent surface water bodies (Lapen et al., 2008), the implications of tile drainage management upon downstream pathogen levels and associated human infection risks should be elucidated.

Traditional water monitoring programs report fecal indicator and occasionally pathogen concentrations over time at various monitoring sites, often over many years. Quantitative microbial risk assessment (QMRA) provides a methodological framework to integrate pathogen monitoring data and epidemiological data to quantify the potential risk to humans (often defined as the probability of infection) associated with various exposure pathways. Ideally, human health risk assessment associated with agricultural BMPs like tile drainage management should be considered in conjunction with environmental and/or production-based BMP performance indicators to better evaluate BMPs using a broader range of formally quantified and documented benefits and consequences. QMRA is a useful tool for comparing risks (in a relative versus absolute way) in various settings, to identify data gaps and guide research. Second-order modelling is useful to more fully consider uncertainty in the analysis and to identify where additional data would help refine our understanding of a system.

The overriding purpose of this study is to provide a quantitative framework that can be used to assess and compare the relative public health significance of watershed microbial water quality associated with agricultural BMPs. Specifically, QMRA models, based upon hypothetical recreational exposures to the zoonotic bacterial pathogen *Campylobacter* spp., were used to examine relative exposure risk in two similar watersheds with widespread use of tile drainage, of which one watershed has tile drainage management practices prolifically employed. Results from these models are compared with *Campylobacter* spp. risks from monitoring sites in other watersheds in the study region to contextualize the results relative to sites featuring different land uses and stream orders. A heuristic, tiered approach to environmental monitoring of microbial water quality at watershed scales was used, evolving from fecal indicator bacteria data to pathogen presence/absence data to quantitative pathogen data.