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Modeling spatiotemporal bacterial variability with meteorological and watershed land-use characteristics

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ABSTRACT

Bacteria are a primary contaminant in natural surface water. The instream concentration of fecal coliform, a potential indicator of pathogens, is influenced by meteorological conditions and land-use characteristics. However, the relationships between these conditions and fecal coliforms are not fully understood. Furthermore, the sources of large variability in fecal coliform counts, e.g., temporal or spatial sources, remain unexplained, especially at large scales. This study proposes the use of Bayesian overdispersed Poisson models, whereby the combined effects of temperature, rainfall, and land-use characteristics on fecal coliform concentration are quantified with predictive uncertainty, and the sources of variability in fecal coliform concentration are assessed. The models were developed using 8-year weekly observations of fecal coliforms obtained from the Wachusett Reservoir watershed in Massachusetts, USA. The results highlight the importance of interactions among meteorological and land-use characteristics in controlling the instream fecal coliform concentration; the increase in fecal coliform concentration with temperature increase was more drastic when rainfall occurred. Also, the responses of fecal coliforms to temperature increases were more pronounced in forest-dominated than in urban-dominated areas. In contrast, the fecal coliform concentration increased more rapidly with rainfall increases in urban-dominated than in forest-dominated areas. The models also demonstrate that among the sources of variability, the monthly component made the most significant contribution to the variability in fecal coliform concentrations. Our results suggest that seasonally dependent processes, including surface runoff, are critical factors that regulate fecal coliform concentration in streams.

1. Introduction

Concerns about fecal coliforms in surface water have increased as drinking water sources have frequently become contaminated by various pathogens over the past decades (Pandey et al., 2014). Although the occurrence of fecal coliforms is not directly related to the presence of pathogens, it can imply a potential risk to human health (Noble et al., 2003). In the United States, the US Environmental Protection Agency (US EPA) has authorized approximately 5600 out of 27,000 known Total Maximum Daily Loads (TMDLs) that are associated with pathogen bacteria (Gronewold and Borsuk, 2010). European countries have established acceptable fecal coliform concentrations for coastal waters (European Communities, 1976, 2002).

Fecal coliforms usually originate from the feces of warm-blooded mammals (i.e., wildlife, livestock, and humans) and birds (Meays et al., 2004). In a watershed, surface water may receive fecal coliforms from different paths, including accidental fecal release from failing septic tanks, combined sewer overflows (CSOs), bacterial runoff from pastures or agricultural areas, and bacterial resuspension from streambeds (Howell et al., 1995; Alderisio and DeLuca, 1999; Gerba et al., 2000; Guber et al., 2006; Servais et al., 2007; Cho et al., 2010a, 2010b, 2012; Pachepsky and Shelton, 2011). Most fecal sources are categorized as non-point sources;

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