WATER RESEARCH 44 (2010) 4776–4782

Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Fecal coliform accumulation within a river subject to seasonally-disinfected wastewater discharges

*Azalea A. Mitch, Katherine C. Gasner, William A. Mitch**

Department of Chemical Engineering, Yale University, Mason Lab 313b, 9 Hillhouse Avenue, New Haven, CT 06520, United States

ARTICLE INFO

Article history:
Received 17 December 2009
Received in revised form
17 May 2010
Accepted 18 May 2010
Available online 12 June 2010

Keywords:
Fecal coliform
Seasonal disinfection

ABSTRACT

As pathogen contamination is a leading cause of surface water impairment, there has been increasing interest in the implications of seasonal disinfection practices of wastewater effluents for meeting water quality goals. For receiving waters designated for recreational use, disinfection during the winter months is often considered unnecessary due to reduced recreational usage, and assumptions that lower temperatures may reduce pathogen accumulation. For a river subject to seasonal disinfection, we sought to evaluate whether fecal coliforms accumulate during the winter to concentrations that would impair river water quality. Samples were collected from municipal wastewater outfalls along the river, as well as upstream and downstream of each outfall during the winter, when disinfection is not practiced, and during the summer, when disinfection is practiced. During both seasons, fecal coliform concentrations reached 2000–5000 CFU/100 mL, nearly an order of magnitude higher than levels targeted for the river to achieve primary contact recreational uses. During the summer, wastewater effluents were not significant contributors to fecal coliform loadings to the river. During the winter, fecal coliform accumulated along the river predominantly due to loadings from successive wastewater outfalls. In addition to the exceedance of fecal coliform criteria within the river, the accumulation of wastewater-derived fecal coliform along the river during the winter season suggests that wastewater outfalls may contribute elevated loads of pathogens to the commercial shellfish operations occurring at the mouth of the river. Reductions in fecal coliform concentrations between wastewater outfalls were attributed to dilution or overall removal. Combining discharge measurements from gauging stations, tributaries and wastewater outfalls to estimate seepage, dilution between wastewater outfalls was estimated, along with the percentage of the river deriving from wastewater outfalls. After accounting for dilution, the residual reductions in fecal coliform concentrations observed between outfalls were attributed to actual fecal coliform removal. The estimated rate of removal of 1.52 d^{-1} was significantly higher than die-off rates determined by previous researchers at similarly low temperatures in laboratory batch experiments, indicating the potential importance of other removal mechanisms, such as predation or sedimentation.

* *Corresponding author*. Tel.: +1 203 432 4386; fax: +1 203 432 4387.
E-mail address: william.mitch@yale.edu (W.A. Mitch).

0043-1354/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.watres.2010.05.060

1. Introduction

Pathogens are amongst the most important causes of water body impairments in the United States. High levels of pathogenic bacteria found in impaired waterways present a health risk to bathers (Boehm et al., 2002; Liu et al., 2006), non-contact recreational users such as anglers and boaters (Donovan et al., 2008; Hellweger and Masopust, 2008), and consumers of raw or undercooked shellfish such as oysters (Ueki et al., 2005; LeGuyader et al., 1996; Formiga-Cruz et al., 2002). In addition to the health risks to humans, pathogen contamination can incur serious economic hardships on communities due to the closure of beaches or shellfish beds.

Pathogen loadings derive from non-point source inputs from urban or agricultural activities (Petersen et al., 2005; Dorner et al., 2004), dry weather flows from storm sewers (Boehm et al., 2002), wet weather loadings from combined or sanitary sewer overflows (Donovan et al., 2008), or discharges from wastewater treatment plants. Attempts to develop water quality models to predict violations of pathogen standards have combined pathogen inactivation and hydrodynamic models. Inactivation models incorporate results obtained from laboratory (Medema et al., 1997) or mesocosm (Sinton et al., 2002; Dutka and Kwan, 1980; Easton et al., 2005) studies to predict pathogen die-off as a function of nutrient and toxin concentrations, pH, temperature, salinity, sunlight and predation. Hydrodynamic models are employed to track pathogen plumes and account for their dilution. These models assess advection and dispersion as well sedimentation and resuspension of pathogens from sediments (Hellweger and Masopust, 2008). In the cases of lakes and oceans, these models have also incorporated the effects of wind-driven currents and tides (Boehm et al., 2002; Liu et al., 2006). At their most complex, these models have solved two or three dimensional advection and dispersion equations within a finite element framework (Hellweger and Masopust, 2008; Liu et al., 2006).

Evaluating the fate of pathogens discharged to rivers can be even more complex. In oceans, lakes (Liu et al., 2006) and dammed rivers that behave like lakes (Hellweger and Masopust, 2008), hydrodynamic models have tracked plumes associated with individual wastewater outfalls or other point discharges. Rivers, however, feature multiple pathogen loading inputs from both point and non-point sources along their course such that pathogens may accumulate within the same plume. Furthermore, water withdrawals along the river may remove pathogens while water inputs from uncontaminated tributaries and groundwater seepage may result in dilution. A previous study addressed these complications by tracking the transport downstream of a non-native bacterial culture spiked into a river; however, only presence/absence data were obtained (Dutka and Kwan, 1980).

Seasonal disinfection of municipal wastewater effluents is permitted in many locations. Where the designated beneficial use of the receiving water is for recreational uses, regulatory agencies may deem disinfection of wastewater effluents during the winter months unnecessary, due to the reduction in recreational activities. However, the implications of these policies for water quality in both the primary receiving waters and in other waters to which these receiving waters discharge have not been a focus of previous research. In this paper, we evaluated the fate and transport of wastewater-derived fecal coliform within a river system. Designated for recreational use, the river system is subject to seasonal disinfection of municipal wastewater effluents. We measured fecal coliform accumulation along the river during the winter months, and evaluated overall fecal coliform removal rates within the river. Our results raised questions about the implications of seasonal disinfection for public health risks associated with recreational use along the river and shellfish harvesting activities conducted at the mouth of the river.

2. Experimental section

2.1. Study site

The Quinnipiac River is located in central Connecticut, originating in Deadwood Swamp north of the Town of Southington and flowing southerly for 61 km to New Haven, where it empties into Long Island Sound (Fig. 1). In a previous study, we had employed boron as a conservative tracer to evaluate the fate of wastewater-derived precursors of nitrosamine disinfection by-products within this river (Schreiber and Mitch, 2006). Registered and permitted activities include 103 water withdrawals and 19 discharges. Five of the dischargers are municipal wastewater treatment plants; from north to south: Southington, Cheshire, Meriden, Wallingford and North Haven (Schreiber and Mitch, 2006). Only the four most northerly wastewater treatment plants were evaluated for this study because the section of the river near the North Haven facility is influenced by tidal action. Eight tributaries empty into the Quinnipiac River between Southington and Wallingford (Table 1): Misery and Honeypot Brooks between the Southington and Cheshire outfalls, Broad, Sodom and Harbor Brooks between the Cheshire and Meriden outfalls, and Meetinghouse Brook and two small unnamed brooks between the Meriden and Wallingford outfalls. One active USGS gauging station is located upstream of the Southington outfall, prior to the conjunction of the Quinnipiac River with the Eightmile and Tenmile Rivers. An additional USGS gauging station is located just upstream of the Wallingford outfall. Shellfish breeding beds are located at the mouth of the Quinnipiac River in New Haven harbor.

2.2. Regulatory framework

The Quinnipiac River falls under two types of regulatory frameworks. Under the authority of the Connecticut Department of Environmental Protection (CT DEP), the Quinnipiac River is designated for recreational uses including swimming, fishing and boating. Used as indicator bacteria, *Escherichia coli* (*E. coli*) levels in the river must remain below a geometric mean of 126 CFU/100 mL and a single sample maximum of 576 CFU/100 mL. To achieve these criteria, the CT DEP issued wastewater treatment plants National Pollutant Discharge Elimination System (NPDES) permits whereby fecal coliform levels, used as indicator bacteria, must be below a geometric