WATER RESEARCH 59 (2014) 23–36

Available online at www.sciencedirect.com

ScienceDirect

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

Effect of submarine groundwater discharge on bacterial indicators and swimmer health at Avalon Beach, CA, USA

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ARTICLE INFO

Article history:
Received 6 November 2013
Received in revised form
21 February 2014
Accepted 18 March 2014
Available online 29 March 2014

Keywords:
Indicator organisms
Water quality
Marine water
qPCR
Gastrointestinal illness

ABSTRACT

Use of fecal indicator bacteria (FIB) for monitoring beach water quality is based on their co-occurrence with human pathogens, a relationship that can be dramatically altered by fate and transport processes after leaving the human intestine. We conducted a prospective cohort study at Avalon Beach, California (USA), where the indicator relationship is potentially affected by the discharge of sewage-contaminated groundwater and by solar radiation levels at this shallow, relatively quiescent beach. The goals of this study were to determine: 1) if swimmers exposed to marine water were at higher risk of illness than non-swimmers; 2) if FIB measured in marine water were associated with swimmer illness, and; 3) if the associations between FIB and swimmer health were modified by either submarine groundwater discharge or solar radiation levels. There were 7317 individuals recruited during the summers of 2007–08, 6165 (84%) of whom completed follow-up within two weeks of the beach visit. A total of 703 water quality samples were collected across multiple sites and time periods during recruitment days and analyzed for FIB using both culture-based and molecular methods. Adjusted odds ratios (AOR) indicated that swimmers who swallowed water were more likely to experience Gastrointestinal Illness (GI Illness) within three days of their beach visit than non-swimmers, and that this risk was

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http://dx.doi.org/10.1016/j.watres.2014.03.050
0043-1354/

significantly elevated when either submarine groundwater discharge was high (AOR [95% CI]:2.18 [1.22–3.89]) or solar radiation was low (2.45 [1.25–4.79]). The risk of GI Illness was not significantly elevated for swimmers who swallowed water when groundwater discharge was low or solar radiation was high. Associations between GI Illness incidence and FIB levels (*Enterococcus* EPA Method 1600) among swimmers who swallowed water were not significant when we did not account for groundwater discharge, but were strongly associated when groundwater discharge was high (1.85 [1.06, 3.23]) compared to when it was low (0.77 [0.42, 1.42]; test of interaction: $P = 0.03$). These results demonstrate the need to account for local environmental conditions when monitoring for, and making decisions about, public health at recreational beaches.

The views expressed in this article are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.

1. Introduction

Public health risk from exposure to sewage-contaminated recreational waters has been recognized in the United States since the 1920's (Simons et al., 1922; Stevenson, 1953). The wide variety of pathogens that may be present in recreational waters makes testing for individual pathogens impractical. For example, more than 100 human enteric viruses may be transmitted by human feces and testing for each of these on a regular basis would be logistically infeasible (Puig et al., 1994). Instead, public health monitoring networks measure a limited set of fecal indicator bacteria (FIB) that correlate with the presence of fecal contamination and human health risk. These FIB include organisms such as *Enterococcus,* fecal coliforms, and total coliforms. Based on a series of epidemiologic studies, the U.S. EPA issued recommended national regulatory criteria for acceptable levels of FIB in recreational waters to protect public health (U.S. EPA, 2012).

One challenge in applying national criteria to individual beaches is that the relationship between FIB and pathogens that co-occur in sewage can be altered by differential fate and transport after discharge. The result may be a dissimilar FIB-health relationship than that used to inform national criteria. In some instances, the FIB source may discharge directly to the surf zone, indirectly to a fresh surface water source (i.e., creek or river) that then discharges to the surf zone (Haile et al., 1999), and/or through the sand via submarine groundwater discharge (Boehm et al., 2003). Many beaches have multiple contamination sources, with the dominant source varying depending on environmental conditions. For example, FIB contributions from land-based runoff may dominate when flow is high, but feces from birds at the beach may dominate at other times, with flow rate affecting the human health relationships with FIB (Converse et al., 2012; Colford Schiff et al., 2012; Schoen and Ashbolt, 2010; Haile et al., 1999; Calderon and Mood, 1991). Similarly, the dominant FIB source at a beach impacted by sewage-contaminated groundwater may vary with submarine groundwater discharge rates (Boehm et al., 2009; Russell et al., 2013). Health relationships have been well-documented for direct discharges from publicly owned treatment works to beaches and inputs to fresh surface water sources that discharge to a beach (see Wade et al., 2003 for a review). However, no epidemiology study of FIB discharged to a beach site via contaminated groundwater has been conducted.

Avalon Beach, located on Catalina Island 42 km west of Los Angeles, is one of the most polluted marine beaches in California (Heal the Bay 2012, California Department of Public Health 2011). The quiescent beach is approximately 500 m long and protected from waves by jetties. The City of Avalon has a population of approximately 3500 year-round residents, but swells with roughly one million visitors in the summer tourist season. Avalon Beach suffers from an aging infrastructure that utilizes salt water in its sewerage system, which contributes to corrosion (Boehm et al., 2003). The City of Avalon and the State of California have invested in inspecting, repairing, and replacing much of the sewerage infrastructure, but beach water quality has remained poor (Heal the Bay, 2012).

Previous work has investigated the sources, fate, and transport of microbial pollution at this beach. For example, Boehm et al. (2003) detected human-specific bacteria and enterovirus in shoreline samples and beach groundwater samples at Avalon Beach. Using a mass balance model of FIB, Boehm et al. (2009) found that inputs from submarine groundwater discharge to the surf zone, combined with losses due to solar inactivation and mixing, explained the hourly time series of *Escherichia coli* and enterococci measured adjacent to the shoreline. In this model, the surf zone was considered a well-mixed prism that changed volume with the tides and alongshore transport was neglected. Thus, residence time of beach water within the prism was related to the tidal condition and was estimated to have a median of 7 h. These results suggest that submarine groundwater discharge contaminated with sewage exfiltrates at the shoreline at Avalon Beach and represents a potentially important source of infectious material to swimmers.

Another potential influence on the levels of infectious material found in marine waters that may be less beach-specific is solar radiation. UVB and UVA radiation in particular have been associated with the inactivation of aquatic organisms including bacteria and waterborne human pathogens (Häder et al., 2011; Noble et al., 2004). Solar UV may limit motility, orientation, activity, and damage the DNA of such