Water Research 111 (2017) 318–329

Contents lists available at ScienceDirect

Water Research

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

Evaluation of the dry and wet weather recreational health risks in a semi-enclosed marine embayment in Southern California

Keah-Ying Lim [a], Stella Shao [b], Jian Peng [b], Stanley B. Grant [a], Sunny C. Jiang [a, *]

[a] *Department of Civil and Environmental Engineering, University of California, Irvine, CA, United States*
[b] *Orange County Environment Resources, Orange, CA, United States*

ARTICLE INFO

Article history:
Received 1 August 2016
Received in revised form
7 December 2016
Accepted 2 January 2017
Available online 4 January 2017

Keywords:
Fecal indicator bacteria
Beach water
Recreational health risk
Risk assessment
Non-point source
Stormwater

ABSTRACT

For many coastal regions around the world, recreational beach water quality is assessed using fecal indicator bacteria (FIB). However, the utility of FIB as indicators of recreational water illness (RWI) risk has been questioned, particularly in coastal settings with no obvious sources of human sewage. In this study we employed a source-apportionment quantitative microbial risk assessment (SA-QMRA) to assess RWI risk at a popular semi-enclosed recreational beach in Southern California (Baby Beach, City of Dana Point) with no obvious point sources of human sewage. Our SA-QMRA results suggest that, during dry weather, the median RWI risk at this beach is below the U.S. EPA recreational water quality criteria (RWQC) of 36 illness cases per 1000 bathers. During wet weather, the median RWI risk predicted by SA-QMRA depends on the assumed level of human waste associated with stormwater; the RWI risk is below the EPA RWQC illness risk benchmark 100% of the time provided that <2% of the FIB in stormwater are of human origin. However, these QMRA outcomes contrast strongly with the EPA RWQC for 30-day geometric mean of enterococci bacteria. Our results suggest that SA-QMRA is a useful framework for estimating robust RWI risk that takes into account local information about possible human and non-human sources of FIB.

1. Introduction

Public beaches in the United States are often monitored for fecal contamination using fecal indicator bacteria (FIB), a broad group of enteric bacteria that are present at high concentrations in human and animal waste (U.S. EPA, 2012). FIB are not a direct measure of the fecal-oral pathogens responsible for most recreational water illness (RWI) (Boehm et al., 2009), but they have been universally adopted as an indicator of fecal pollution based on two considerations: (1) epidemiological studies have long demonstrated a significant correlation between RWI rates and swimming in sewage-contaminated recreational waters containing elevated concentrations of FIB, in particular enterococci bacteria (ENT) in marine waters (Prüss, 1998) and; (2) they are relatively easy and inexpensive to measure using culture-based methods (Boehm and Soller, 2013). However, many recent studies have shown that the correlation between ENT and RWI weakens when the bacteria originate from non-point sources (e.g., runoff, bird waste) and not human fecal pollution (Arnold et al., 2013; Colford et al., 2012; Colford Jr. et al., 2007; Fleisher et al., 2010). As a result, the marine RWI health risks implied by ENT measurements are likely to be site-specific, as acknowledged in the most recent recreational water quality criteria (RWQC) published by the U.S. EPA in 2012 (U.S. EPA, 2012). Indeed, the 2012 RWQC offers beach managers the flexibility to develop site-specific water quality criteria based on epidemiological studies, quantitative microbial risk assessment (QMRA), and/or sanitary surveys (U.S. EPA, 2012). The new RWQC includes both FIB-based criteria, such as the 30-day geometric mean (GM) and statistical threshold value (STV), as well as the illness-based criteria derived from epidemiological studies.

The FIB-based criteria are generally used as the default approach for assessing RWI risk because of the high cost of epidemiological studies. However, this default approach does not distinguish between different sources of FIB, but rather compares FIB measurements to RWQC as an indirect risk management approach. At the mean time, recent epidemiological studies at beaches impacted by non-point source pollution (such as runoff) demonstrate: (1) a weak or non-existent correlation between FIB and RWI; and (2) increased illness risk for bathers compared to non-bathers, possibly indicating the presence of fecal-oral pathogens (Arnold et al., 2013; Colford et al., 2012; Colford et al., 2007; Fleisher et al., 2010). These

* Corresponding author. University of California, Irvine, CA 92697, United States.
E-mail address: sjiang@uci.edu (S.C. Jiang).

http://dx.doi.org/10.1016/j.watres.2017.01.002
0043-1354/

Abbreviations used

BMPs	Best Management Practices
ENT	Enterococcus
FC	Fecal coliforms
FIB	Fecal indicator bacteria
GM	Geometric mean
MST	Microbial source tracking
QMRA	Quantitative microbial risk assessment
SA-QMRA	Source apportionment quantitative microbial risk assessment
STV	Statistical threshold value
RWI	Recreational water illnesses
RWQC	Recreational Water Quality Criteria
TC	Total coliforms
TMDL	Total Maximum Daily Load
U.S. EPA	United States Environmental Protection Agency

epidemiological results are consistent with many field studies conducted over the years that demonstrate a disconnection between FIB concentrations in recreational waters and the presence or absence of human viruses responsible for most RWI, such as norovirus and adenovirus. In some cases FIB concentrations are elevated when viral pathogens are absent, while in other cases FIB concentrations are low when viral pathogens are present (Jiang et al., 2007; Love et al., 2014; McQuaig et al., 2012). The underlying reasons for this disconnection are complex and site-specific, but include: (1) the existence of multiple environmental reservoirs for FIB, such as sediments (Piggot et al., 2012), algae (Whitman et al., 2003), and the water column itself (Surbeck et al., 2006); and (2) the different environmental fate and transport characteristics of FIB and viral pathogens (Byappanahalli et al., 2012). The net result is that strict enforcement of FIB criteria can lead to a misrepresentation of the true health risk, either by unnecessarily posting beaches as unfit for recreating (with attendant loss of the socio-economic benefits) or not warning the public when a true health risk exists (resulting in RWI and attendant economic losses) (Given et al., 2006; Kim and Grant, 2004).

The problems outlined above beg for a more tailored and holistic approach to beach water quality monitoring and public notification that specifically considers the location, hydrometeorologic conditions (Surbeck et al., 2006), historical water quality data (Boehm et al., 2002), and possible sources of both fecal and non-fecal FIB (Abdelzaher et al., 2011; McQuaig et al., 2012). Recently, a Source Apportionment Quantitative Microbial Risk Assessment (SA-QMRA) framework was proposed for evaluating RWI health risks in recreational waters not affected (or at least not primarily affected) by point sources of human sewage (Soller et al. 2010b, 2014, 2015). The SA-QMRA framework simulates RWI risks based on the variety of different FIB sources at a particular beach, for example from seagulls, humans, pigs, cows, or mixed sources. FIB-to-pathogen ratios for various beach-specific point and non-point sources are used to infer human pathogen concentrations (the causative agents for RWI) from shoreline measurements of FIB concentration. The FIB sources can be informed by sanitary surveys of the site, and microbial source tracking (MST) techniques (Fung et al., 2007; Sercu et al., 2008). In principle, the SA-QMRA framework can also account for how runoff from separate storm sewer systems is locally managed. For example, at many coastal sites in Southern California, dry weather runoff is diverted to wastewater treatment plants with documented benefits for coastal water quality (Dorsey, 2010). In addition to providing a more tailored approach for assessing RWI risk and public water quality notifications, the SA-QMRA approach can enable scenario testing, for example to assess how health risks might change under different mixes of human and non-human fecal sources, different FIB-to-pathogen ratios, or a changing climate.

While SA-QMRA has been applied to hypothetical scenarios, it has not yet been applied to an actual test case due to the challenge of quantitative apportionment of fecal sources. However, as demonstrated in this study the source apportionment process can be achieved through meta-analysis of relevant literature and a survey of the available site-specific data in the form of local reports and grey literature. In this paper we apply the SA-QMRA framework to Baby Beach in Dana Point, Orange County, California. This particular beach has suffered elevated FIB concentrations for a number of years, and is included on the State Water Quality Control Board Clean Water Act Section 303(d) List (State Water Resources Control Board, 2004). A number of best management practices (BMPs) have been put in place to reduce FIB pollution at this site, including beach clean-up and dry weather runoff diversion. While these activities appear to have reduced the concentrations of total coliforms (TC) and fecal coliforms (FC), concentrations of ENT are still frequently in excess of the 2012 RWQC during both wet and dry periods. Accordingly, the main objective of this study was to quantify, using SA-QMRA, the dry weather and wet weather RWI risks associated with the ENT measurements at Baby Beach. Our results demonstrate the potential utility of this approach for providing robust RWI risk assessments, and more generally demonstrate the power of a risk assessment approach to beach water quality management.

2. Materials and methods

2.1. Site description

The study site is located at Baby Beach, a small man-made and semi-enclosed beach in Dana Point Harbor, California with approximately 183 m long of recreational shoreline (Fig. 1). Protected by two breakwaters from the Pacific Ocean, the shoreline of Baby Beach is characterized by warm and calm water, which makes the beach a popular family destination that receives an estimated 1 million visitors annually. The catchment basin of Baby Beach drains an area of 175,630 m^2, which covers undeveloped open spaces with some residential and commercial land uses. The region receives annual rainfall averaged around 325 mm (Orange County Public Works).

In contrary to the seemingly child-friendly water it offers, Baby Beach has had historically high FIB level that are considered as “unsafe” for recreational uses. After an eleven months initial closure of the beach in 1996 and a two-month health risk advisory posting at the beach in 2002 due to elevated FIB levels, massive investigative measures have been taken to lower the FIB level of the beach (County of Orange & City of Dana Point, 2011). The most notable actions were the construction of a dry weather runoff diversion near the main storm drain line in late 2005 that resulted in close-to-zero runoff to the beach during the summer/dry season (April 1st to October 31st each year), as well as the installation of media filter vaults for filtering the stormwater when the dry weather diversion is not in effect (November 1st to March 31st each year).

2.2. Data source

The ENT concentrations at four sampling points along the recreational shorelines of Baby Beach (BDP12, 13, 14, 15 in Fig. 1) since