WATER RESEARCH 44 (2010) 4692–4703

Available at www.sciencedirect.com

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

Predicting pathogen risks to aid beach management: The real value of quantitative microbial risk assessment (QMRA)☆

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ARTICLE INFO

Article history:
Received 1 April 2010
Received in revised form
14 June 2010
Accepted 21 June 2010
Available online 26 June 2010

Keywords:
Recreational water
Quantitative microbial risk assessment
QMRA
Bathing water
Beach management

ABSTRACT

There has been an ongoing dilemma for agencies that set criteria for safe recreational waters in how to provide for a seasonal assessment of a beach site versus guidance for day-to-day management. Typically an overall 'safe' criterion level is derived from epidemiologic studies of sewage-impacted beaches. The decision criterion is based on a percentile value for a single sample or a moving median of a limited number (e.g. five per month) of routine samples, which are reported at least the day after recreator exposure has occurred. The focus of this paper is how to better undertake day-to-day recreational site monitoring and management. Internationally, good examples exist where predictive empirical regression models (based on rainfall, wind speed/direction, etc.) may provide an estimate of the target faecal indicator density for the day of exposure. However, at recreational swimming sites largely impacted by non-sewage sources of faecal indicators, there is concern that the indicator-illness associations derived from studies at sewage-impacted beaches may be inappropriate. Furthermore, some recent epidemiologic evidence supports the relationship to gastrointestinal (GI) illness with qPCR-derived measures of *Bacteroidales/Bacteroides* spp. as well as more traditional faecal indicators, but we understand less about the environmental fate of these molecular targets and their relationship to bather risk. Modelling pathogens and indicators within a quantitative microbial risk assessment framework is suggested as a way to explore the large diversity of scenarios for faecal contamination and hydrologic events, such as from waterfowl, agricultural animals, resuspended sediments and from the bathers themselves. Examples are provided that suggest that more site-specific targets derived by QMRA could provide insight, directly translatable to management actions.

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1. Introduction

The past two decades have seen many significant advances in environmental microbiology pertinent to the better management of pathogen risks to bathers/recreators in natural waters. Microbiologists and engineers have utilized hydrodynamic modelling to provide insights into microbial contaminant movement (Falconer et al., 2001; Harris et al., 2004; Kashefipour et al., 2002; Kay et al., 2005; Lin et al., 2008). For example, the processes of inactivation, and in

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0043-1354/$ – see front matter Published by Elsevier Ltd.
doi:10.1016/j.watres.2010.06.048

particular the critical role of solar radiation are better understood (Davies et al., 2009; Davies-Colley et al., 1994; 2000, 2005; Guillaud et al., 1997; Johnson et al., 1997; Sinton et al., 2007, 2002; Sinton, 2005). Further, improved knowledge has become available on the causative agents of water-associated illness, particularly enteric viruses (Jones et al., 2009; Sinclair et al., 2009; Soller et al., 2010a). From a microbial ecology context, there has been a revolution in our understanding of gut microbioms (microbial diversity) that has resulted from various genomic approaches (Allen and Banfield, 2005; Zaneveld et al., 2010), which may provide for improved host-specific targets in the future (Santo Domingo et al., 2010). Finally there has been increasing application of risk assessment to inform management actions (Gerba et al., 1996; Kay et al., 1994, 2004; Roser et al., 2007; Soller et al., 2010b).

Nonetheless, we do not generally see this suite of new approaches reflected in how the microbiological safety of recreational waters is managed, nor is it clear how to deal with locations that have high temporal and spatial variability (e.g. Boehm, 2007). Rather, current management approaches still largely focus on sampling beach waters and returning a water quality statistic possessing many uncertainties, days after swimmer exposure has occurred or averaging samples collected over multiple dates to generally characterize a beach/bathing site (European Union, 2006, US-EPA, 1996). More recent emphasis has been placed on two developments. The first has focused on improvements for day-to-day management through developing and validating rapid (same-day) faecal indicator organism (FIO) assays (Haugland et al., 2005; Wade et al., 2006). Secondly, there has been a large effort devoted to 'finding a better indicator', more formally "microbial or faecal source tracking and tracing (MST)". For example there has been considerable interest in assaying members of the gut bacterial order *Bacteroidales*, which vastly outnumbers traditional faecal indicator bacteria in the intestinal tracts of humans and other animals (Qin et al., 2010). Other potential target groups are various faecal bacteriophages (Rosario et al., 2009), because they are conceptually better models of human enteric virus behaviour in the environment than faecal indicator bacteria (Ashbolt et al., 2001). Within this context, enteric viruses are commonly thought to be the major aetiologic agents capable of causing observed recreator gastroenteritis in waters impacted by human sources (Schoen and Ashbolt, 2010; Sinclair et al., 2009; Soller et al., 2010a).

Primarily, members of the *Bacteroidales* order appear to be the current emerging MST targets of choice (Field and Samadpour, 2007; Santo Domingo et al., 2007), and assays using quantitative polymerase chain reaction (qPCR) estimate densities, which along with qPCR-targeted enterococci, both appear to be useful health surrogates at sewage-impacted beaches (Wade et al., 2006). Yet our limited ecologic understanding of *Bacteroidales* is raising possible concerns (Bae and Wuertz, 2009; Stapleton et al., 2009; Walters and Field, 2009), comparable to those identified for the established FIO (Santo Domingo et al., 2010). As a consequence, the universal use of FIOs as the primary indices of illness risks to bathers is questionable for the range of possible contamination sources (Boehm et al., 2009; Dorevitch et al., 2010).

This paper presents a view that we need to balance our current microbiology method-driven approach to managing recreational water needs against other alternatives; in particular a more holistic analysis of recreation risks, with the goal of providing safe recreational waters. An illustrative example of this different approach is the application of empirical models to rapidly and cost effectively predict FIO densities and provide direct management information to control bathing (Francy, 2009; McPhail and Stidson, 2009, NSW-EPA, 2000). The World Health Organization (WHO) has been proactive in trying to promote such a balance, through the introduction of 'sanitary surveys' for the management of safe recreational waters (WHO, 2003). New Zealand, Australia and the European Union have followed up with the inclusion of sanitary surveys in their guidelines, yet full uptake of the WHO concept is not mainstream. Not undertaking and interpreting the sanitary survey misses the underlying principle that "knowing your beach catchment" should be the first step in developing beach management strategies. In the U.S., new criteria are planned to be issued in 2012, and sanitary surveys, amongst other options, are under consideration.

During the 20th century, sanitary engineers were required to understand the pollutant sources and behaviours of their water system, because of previous inadequate and time-consuming microbiology methods. So it is somewhat ironic that we seem to have traded this common sense approach to understanding beach pollution dynamics for a primary focus on developing a rapid 'high-tech' method to estimate faecal contamination without consideration of the wider environmental context. More holistic analysis is needed even where empirical predictive models appear useful for day-to-day management (particularly for sewage-impacted beaches) because, these are too dependent on the assumption of a fixed FIO-health relationship. The additional 'tool' we propose to aid in our understanding of pathogens in beach waters, is quantitative microbial risk assessment (QMRA), which is also supported by WHO (2003) and the US-EPA (2007). By this we do not mean only the endpoint calculation of risk in terms of infection probabilities or other end points currently being rolled out for the protection of drinking water, but the conceptualisation and quantification of pathogen sources and barriers, including dilution and transport more generally.

This paper reviews major issues in managing safe recreational waters. It describes how QMRA can be used to 'fill-in-the-gaps' of knowledge about numerous scenarios that may lead to faecal pollution at recreational sites, which can provide managers with timely and quantitative information to better manage recreator safety in various aquatic environments.

2. Risk assessment versus numerical compliance

Cursory examination of the WHO (2003) model guidelines suggests that they are essentially the same as the earlier generation of various regulations used internationally. As such they present a list of rules to be applied locally according to preference and legal system etc., with their main difference