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Research paper

Modeling pathogens for oceanic contact recreation advisories in the New York City area using total event simulations

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ABSTRACT

A simulation of transport and fate of pathogen indicators for the New York City open waters was completed using a coupled numerical model. Modeled concentrations for Enterococci in receiving waters were extracted from the model and compared with NYC beach observations and NYC Harbor Surveys to validate and bias-correct the result. Results, both before and after bias-correction, were then used to calculate model-based contact recreation advisories and compare to existing advisories: NYC DEP advisory guidance for waterbodies, and NYC DOHMH advisory guidance for NYC beaches. The model was able to simulate the transport and fate of Enterococci. Receiving water Enterococci concentrations grew responsively to rainfall, and decreased notably after rainfall. The model showed the ability to take complexity of natural effects into account, and was conservative in most cases after bias-correction. Based on an exceedance criterion of 110 cfu/100 mL, simulated Enterococci concentrations exceeded that criterion 54% (109%) of the total advisory days that existing NYC DOHMH guidance would suggest throughout all NYC beaches, on average, before (after) bias-correction. The model exceeded that criterion 217% (246%) of the total advisory days that existing NYC DEP guidance would suggest throughout all NYC waterbodies, on average, before (after) bias-correction. Simulation results were provided to NYC DEP and NYC DOHMH for the refinement of existing advisories.

1. Introduction

New York City's (NYC) waste water from its urban drainage areas is directed by its sewer system to Water Pollution Control Plants (WPCP) for sanitary sewage disinfection and treatment. During heavy rain events, storm water also enters the sewer system, combined with sewage, occasionally making the total amount of waste surpass the capacity of the WPCP for treatment. If the total treatment capacity of a WPCP is exceeded, untreated combined sewer overflow (CSO) is discharged into tributaries and open New York/New Jersey Harbor (NY/NJ Harbor) waters.

Pathogen indicators are surrogate organisms that suggest the presence of disease-causing organisms (Gastrich, 1999). The New York City Department of Environmental Protection (NYC DEP, or just DEP hereafter) and the New York City Department of Health and Mental Hygiene (NYC DOHMH, or just DOHMH hereafter) have created public advisories to avoid contact recreation when recently-observed significant rainfall volumes are expected to produce CSO discharges to elevate pathogen indicator concentrations. Each NYC beach is assigned a classification by DOHMH (HydroQual, 2007a), based on the evaluation and evidence of information provided by past history and existing water quality models and data trends, with wet-weather advisories mainly based on rainfall limits (Table 1 Fig. 1). DEP also provides wet weather advisories (NYCDEP, 2016c) for NYC waterbodies (Fig. 2) based on rainfall volume (Table 2) and expected CSO discharge.

Besides CSO discharges, there are other sources of pathogens to receiving waters. In urban areas, urban litter, contaminated refuse, domestic pets and wildlife excrement can contribute to total pathogen loads into receiving water; the level of fecal bacteria is directly related to the density of the housing population, and the development of the area (USEPA, 2001; Young and Thackston, 1999). In rural areas, confined animal operations can be a major pathogen source, as can be areas of nesting waterfowl. Livestock excrement can directly increase pathogen loads during rainfall when manure is not deposited directly into waters (Edwards, 1997). Additional sources like boat discharges, faulty septic systems (Jagupilla et al., 2012; Young and Fellow, 2008) and illicit connec-

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Table 1
DOHMH guidance for wet weather conditions Advisory (NYCDOHMH, 2016b).

Beach(es), Borough	Rainfall Limit	Advisory Duration
Orchard Beach, Bronx	>6.4 cm	24 h
Manhattan Beach, Kingsborough Community College, Brooklyn Midland Beach, South Beach,	3.8–6.4 cm	12 h
Cedar Grove Beach, Staten Island	>6.4 cm	24 h
Coney Island, Brooklyn	>6.4 cm	12 h
Gerritsen Beach, Brooklyn Whitestone Booster, Queens	0.8–1.5 cm	18 h
	>1.5 cm	40 h
Douglaston,	0.8-1.5 cm	30 h
Queens	1.5–6.4 cm	60 h
	>6.4 cm	72 h
All Bronx Private Beaches	1.5–6.4 cm	36 h
	>6.4 cm	48 h

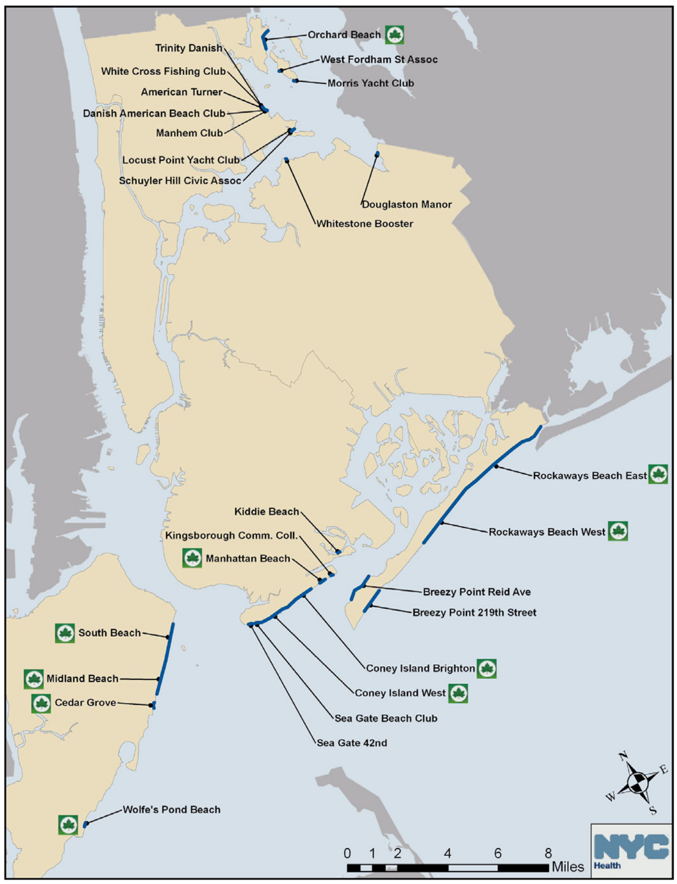

Fig. 1. Locations of NYC beaches (NYCDOHMH, 2016a). Public beaches are highlighted with the green leaf sign. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

tions (NYCDEP, 2016b) can also cause pollution to open waters during dry weather.

Notwithstanding the variety of possible pathogen sources, previous research has also shown that pathogen concentrations can be affected by multiple natural forces. By investigating pathogen indicator densities, pathogen concentrations have been observed to have high – orders of magnitude – variation within a short period of time (less than one hour) at coastal, river and stream sites, partly because of the dilution and mobilization of indicator bacteria, introduced by wave forces (Boehm, 2007; Meays, 2006). Pathogen survival in water is affected by temperature and salinity (Chapra, 1997; Novotny and Olem, 1994). Pathogen indicator bacteria have better chance of survival in fresh water at lower temperature. Solar radiation decreases the density of indicator bacteria during daylight hours and causes diurnal variations in indicator density (Sinton et al., 2002). Tides dilute indicator density through tidal currents by connecting tidal waters and nearshore surface waters (Boehm, 2005). Gao has done experiments of fate and transport of fecal bacteria in estuarine waters with and without tides (Gao et al., 2015). The results show that tides have significant influence over the bacteria distribution. The median bacterial concentration is strongly affected by the tidal processes, but the effect varies from location to location. Due to the complexity in the real environment, a numerical model that includes such processes may be able to provide more accurate and detailed information than a traditional method based solely on rainfall volume.

The 3D receiving water model used to create the rating curves for the current NYC advisories (PATH, a version of SWEM, the System-Wide Eutrophication Model, e.g. HydroQual, 2007a, 2007b) has been used extensively in water quality studies in the NY Harbor, and has a proven record. It has 10 sigma layers in the vertical, and a total of 1654 cells in the horizontal covering the waters