Science of the Total Environment 625 (2018) 809–818

Contents lists available at ScienceDirect

Science of the Total Environment

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

Water Exclosure Treatment System (WETS): An innovative device for minimizing beach closures

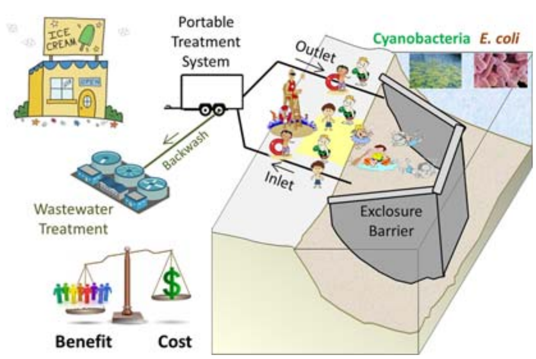
John R. Reimer [a], Chin H. Wu [a,*], Kirsti K. Sorsa [b]

[a] Department of Civil and Environmental Engineering, University of Wisconsin, Madison, WI, USA
[b] Department of Public Health of Madison and Dane County, Madison, WI, USA

HIGHLIGHTS

- A Water Exclosure Treatment System was designed and implemented in an inland beach.
- WETS consists of "exclosure" and treatment sub-systems.
- WETS promotes social-economic benefits for increasing beach user activities.
- WETS reduces turbidity levels inside the exclosure to 15 times less than outside.
- WETS reduces *E. coli*, and *Cylindrospermopsis* sp. to 30, and 16 times less.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 December 2017
Received in revised form 28 December 2017
Accepted 28 December 2017
Available online xxxx

Editor: D. Barcelo

ABSTRACT

A Water Exclosure Treatment System (WETS) is developed and installed to minimize the occurrence of beach closures due to algae and *Escherchia coli* (*E. coli*) in an inland lake. WETS consists of an "exclosure" sub-system with a five-sided polypropylene, barrier that excludes offshore lake contaminated water from the swimming area. Inside the exclosure, water is pumped to a portable filtration-ultraviolet treatment sub-system with three components. First, heavy debris like aquatic plants are removed through a strainer. Second, fine particles are removed through a sand filter and backwashing is automated through a program logic controller triggered by pressure sensor readings. Third, pathogens, algae, bacteria, and viruses are inactivated through ultraviolet (UV) disinfection. To determine sizing of sand filters and evaluation of efficiency of UV disinfection and aid in the design of the inlet and outlet locations for the pump system, computational fluid dynamics modeling with a Lagrangian particle-tracking method are employed. Flushing time is determined to range from 0.67 to 1.89 days. Residence time maps reveal inlet and outlet locations play an important role in depicting the duration of particles within the swimming area. Comprehensive water quality sampling is conducted and analyzed with ANOVA testing reveal that water quality parameters inside the exclosure are significantly different than those outside. There have been no beach closures issued since deployment of WETS. Overall, WETS, an innovative Water Exclosure Treatment System, provides safe, clean water inside the exclosure for minimizing beach closure.

Published by Elsevier B.V.

1. Introduction

Beaches, a large part of the economies worldwide, provide well-being of local residents for swimming opportunities and attract tourism

* Corresponding author.
E-mail address: chinwu@engr.wisc.edu (C.H. Wu).

https://doi.org/10.1016/j.scitotenv.2017.12.330
0048-9697/Published by Elsevier B.V.

(Englebert et al., 2008; Houston, 2008; Wheeler et al., 2012; Ashbullby et al., 2013). Tourism in Wisconsin is a 12 billion dollar per year industry (Kleinheinz, 2003). Nevertheless, poor water quality at beaches can cause health threats or illness problems along shorelines for swimmers or recreational users (Patz et al., 2008). As a precautionary mean for the condition when water quality is below the standard, beach closures are issued. Surveys conducted by the Natural Resources Defense Council showed that over 20,000 beach closures every year were issued in the United States (Dorfman and Haren, 2013), yielding an estimated economic loss of approximately $35 for each person and up to $37,030 per day at a Lake Michigan beach (Rabinovici et al., 2004). Other economic impacts are medical costs to stricken beachgoers (Dwight et al., 2005). A previous study by Given et al. (2006) reported that each year, fecal contamination at Los Angeles and Orange County beaches caused between 627,800 and 1,479,200 gastrointestinal illnesses, resulting in a public health cost of $21 to $51 million USD. Furthermore, a recent study estimated that the cost of illness attributed to freshwater recreation was $1676 per 1000 people engaged in swimming or wading at freshwater and marine locations (DeFlorio-Barker et al., 2017). In view of these consequences, it is of high desire to minimize beach closures to reduce health risk or medical cost and enhance great economic through tourism.

Cyanobacteria and *E. coli* bacteria are two main causes that pose a great health risk to recreation users. Cyanobacteria are a group of photosynthetic bacteria that can produce inherent toxins like hepotoxins, neurotoxins, cytotoxins, dermototoxins, and irritant toxins (Wiegand and Pflugmacher, 2005). Exposure to cyanobacteria hepato- and neurotoxins can cause impaired health or death of livestock wildlife, pets, and humans (Turner et al., 1990; Chorus and Bartram, 1999; Falconer, 1999; Carmichael et al., 2001). Since many cyanobacteria contain gas vacuoles, they can form as floating scum mats regularly reported at downwind shorelines fouling beaches in the Yahara Lakes, Wisconsin (Lathrop et al., 2013). As a result, cyanobacteria scums are considered nuisance due to unaesthetic appearance and offensive odors associated with decomposition (Speziale and Dyck, 1992; Lathrop et al., 2013). Bacteria, present in fecal material, can be transmitted to humans during recreational water use via contaminated water carrying pathogens (McLellan and Salmore, 2003), posing a serious health concern to beach users. Possible sources of fecal organisms include humans (Lee et al., 2014), gulls (Araujo et al., 2014), geese, or domestic animals (Winfield and Groisman, 2003). For water quality monitoring, *Escherichia coli* (*E. coli*) is an indicator for fecal organisms for beach contamination (Kleinheinz and Englebert, 2005). Previous studies have shown that high occurrences of *E. coli* in water are associated with gastrointestinal disorders and other illnesses in swimmers (Dufour, 1984; Dufour and Cabelli, 1986; Pruss, 1998; Wade et al., 2003). Both cyanobacteria and *E. coli* can harbor within filamentous green algae (Whitman et al., 2003; Kleinheinz and Englebert, 2005; Englebert et al., 2008; Badgley et al., 2011; Vijayavel et al., 2013) that can then release free-floating bacteria and cyanobacteria by wave action, storms, and seasonal sloughing (i.e. detaching), accumulating along beach shorelines (Whitman et al., 2003). In general, cyanobacteria and *E. coli* bacteria pose a threat to public health in recreational waters and beaches.

A great deal of efforts has been devoted to improve water quality, decrease contamination, and protect the health of beach users. For example, beach management practices often employed are stormwater runoff practices, combined sewer overflow mitigation, wildlife control, beach sediment nourishment, and source control policies. Based on the origination of contaminant, practices can be generally classified into two, onshore and offshore categories (Przybyla-Kelly et al., 2013). Onshore de-contamination practices like beach grooming are conducted to remove litter, vegetation, detritus, and animal fecal droppings in nearshore sand to reduce microbes harmful to human health (Sabino et al., 2014). As a result, fecal indicator bacteria can be reduced, improving beach water quality (Kinzelman et al., 2004). Similar onshore practice is to alter beach sediments from sand to gravel beaches to decrease concentrations of fecal bacteria (Aragones et al., 2016). Another onshore practice is to deter gull and geese populations from residing at beach areas, reducing bacteria concentration in the swimming water (Converse et al., 2012; Lee et al., 2013). Offshore de-contamination practices use devices to trap, deflect, or block offshore polluted lake water from entering swimming areas. For example, a floating boom to deflect long-shore currents in an inland lake in Wisconsin prevented swimming beaches to become fouled with blue-green algal (cyanobacteria) scums and other floating debris (Lathrop et al., 2013). This boom device was effective for blocking surface floating materials but could not prevent contaminants from entering into the swimming area through the open flowing water underneath of the floating boom. In comparison, a full depth permeable curtain was installed at Harbor Island Beach, New York. The mechanism of tidal fluctuations provides the filtration to remove contaminates, effectively reducing *E. coli* by 81.9% (Lowe, 2008). A similar filtering curtain was installed at Calument Beach, Chicago but the swimming beach trapped more phytoplankton, higher *E. coli*, and turbidity (Przybyla-Kelly et al., 2013), suggesting that the effectiveness of full depth curtains depends on tides or other water motions. To date, little attention has been devoted to develop devices that minimize beach closures in inland, freshwater lakes where tidal effects are not significant.

The objective of this paper is to test the hypothesis that an innovative Water Exclosure Treatment System (WETS) can prevent algal scums and reduce beach closures from cyanobacteria and *E. coli* bacteria originating from either offshore or onshore in inland lakes. The WETS consists of two sub-system: an exclosure consisting of an impermeable curtain at the offshore and a water treatment device at the shore. The design of WETS water treatment intake and outlet piping locations were evaluated using computation fluid dynamics to estimate contaminant flushing and residence time scales. WETS was installed at a pilot beach in 2011 which has experienced contamination from onshore due to resident geese populations and offshore due to floating cyanobacteria scum and bacteria. The effectiveness of WETS in reducing cyanobacteria and *E. coli* concentrations to safe levels for beach users was evaluated. Overall it is found that WETS eliminated the number of beach closures in a non-tidal, freshwater lake.

2. Materials and methods

2.1. Study site

Brittingham Beach is located on the north shore of Monona Bay within the Yahara River Chain of Lakes in Dane County, Wisconsin, (see star location in Fig. 1a). The beach, originally built in 1910, was the City of Madison's first water park boasting an expansive water slide and rental swimsuits. Brittingham Beach was one of the City's most popular beaches nearly 100 years ago. Nevertheless, today it is one of the least frequented beaches due to poor water quality high cyanobacteria and *E. coli* bacteria levels. From 2005 to 2009, the beach was closed 14 days due to high cyanobacteria and *E. coli* levels. As a result, Brittingham Beach was listed on the Environmental Protection Agency (EPA) 303(d) list of impaired beaches for high bacteria levels for several attributes. Onshore contamination is suspected to be a source of *E. coli* due to large numbers of waterfowl (i.e. geese and ducks) residing at the beach. Offshore contamination due to stormwater outfalls exits the shoreline riprap, approximately 350 ft away on each side of the beach. The outfalls drained from an urbanized and mixed use watershed where similar studies have shown that the discharge water contains pollutants such as oil and grease, chemicals, nutrients, metals, and bacteria (Brownell et al., 2007). Since the 1950's, Public Health of Madison and Dane County (PHMDC) has conducted sampling at Brittingham Beach. When water sampling shows elevated levels of cyanobacteria or *E. coli*, beach closing (a passive approach) is issued by PHMDC. Nevertheless, users may swim at their own risk. In this