Ecological Engineering 78 (2015) 72–78

Contents lists available at ScienceDirect

Ecological Engineering

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

Pathogen removal from urban pond outflow using rock biofilters

Marc W. Beutel[a,*], Laurie Larson[b]

[a] Washington State University, Department of Civil and Environmental Engineering, Pullman, WA 99164, United States
[b] Washington State University, Washington Stormwater Center, Puyallup, WA 98371, United States

ARTICLE INFO

Article history:
Received 16 October 2013
Received in revised form 5 March 2014
Accepted 2 May 2014
Available online 7 June 2014

Keywords:
Rock biofilter
Urban pond
Fecal coliform
E. coli
Dissolved oxygen
pH

ABSTRACT

Urban ponds provide a range of unique environmental services, but their setting commonly results in microbial contamination, which can pose a threat to human and ecological health. In an effort to protect receiving waters from microbial contamination, this study evaluated the effectiveness of triplicate horizontal-flow rock biofilters (rock diameter, 2–3 cm; area, 0.45 m^2; hydraulic retention time, 50 min) to remove low levels of fecal coliform (FC) and *Escherichia coli.* (<500 cfu/100 mL) in outflow from DeCoursey Pond, a 0.5 ha urban pond in Puyallup, WA. Within a few weeks of loading, biofilter rocks had visible biofilm growth and over half of the biofilter area was covered with the filamentous green algae *Oedogonium spp*. Algae activity in biofilters produced peak afternoon dissolved oxygen (DO) concentrations as high as 18 mg/L and pH values above 8.5. Levels of areal chlorophyll (42 and 80 mg/m^2) and gross productivity (4.5 and 6.1 g O_2/m^2/d) were equivalent to a mesotrophic stream. Biofilters were effective in removing FC from an average of 262 cfu/100 mL to 98–140 cfu/100 mL (n = 13) and *E. coli* from an average of 243 cfu/100 mL to 96–110 cfu/100 mL (n = 5). There was a weak but significant positive correlation between DO and pH and FC removal in biofilters, possibly because of the ability of oxygen and hydroxide to enhance sunlight-driven inactivation of pathogens. Results showed that rock biofilters, a very simple and inexpensive ecotechnology, are capable of polishing mildly microbially polluted waters to levels below criterion for the protection of surface waters.

1. Introduction

Urban ponds, wetlands and associated parks provide numerous ecological and human benefits (Bolund and Hunhammar, 1999; Konijnendijk et al., 2013). Urban ponds are important habitat for wildlife and enhance biological diversity in urban-dominated landscapes (Gledhill et al., 2008). Urban parks also promote human health and wellbeing by supporting a wide range of recreational opportunities, enhance prices of nearby property, and mitigate urban heating by cooling their surroundings (Konijnendijk et al., 2013). The esthetic environmental experience of urban parks can enhance linkage between humans and nature, potentially reminding urban residence that they are part of a wider natural ecosystem (Meyer, 2008). Urban ponds can also be used as tools to expand ecological awareness in urban residents though outreach and education (Bodzin, 2008). Some urban ponds are actually engineered multi-use stormwater detention basins, which are designed to remove pollutants from urban runoff and dampen urban stormwater hydrographs (Park et al., 2012).

Of particular concern in urban watersheds are microbial pathogens, which pose a significant threat to human health and environmental quality (Arnone and Walling, 2007). Sources of pathogen contamination to urban ponds include resident wildlife and waterfowl and stormwater draining polluted urban surfaces (Stoianov et al., 2000; Shellenbarger et al., 2008). Pathogen pollution from nonpoint sources is a leading cause of water quality impairments in US surface waters (USEPA, 2012a), and is linked to acute and chronic health impacts through exposure to contaminated drinking water, seafood, and recreational water bodies (Gaffield et al., 2003). Pathogen contamination of surface waters results in substantial societal and environmental costs. Millions of waterborne illnesses each year are attributable to exposure to microbially contaminated stormwater (Gaffield et al., 2003). Pathogens pose a serious threats to shellfish harvesting, a special concern in Washington State where the commercial and recreational shellfish industry is valued at hundreds of millions of dollars

* Corresponding author. Tel.: +1 509 334 3721; fax: +1 509 335 7632.
E-mail address: mbeutel@wsu.edu (M.W. Beutel).

http://dx.doi.org/10.1016/j.ecoleng.2014.05.001
0925-8574/

per year (Booth et al., 2006). Every year, tens of thousands of beach closures nationwide, caused by microbial pollution, cost local communities reliant on tourism and recreation thousands of dollars per day (NRDC, 2012).

A number of engineered systems, commonly referred to a best management practices (BMPs), have been developed to remove pollutants from nonpoint sources. Mechanisms of removal and inactivation in BMPs include: direct damage by ultraviolet radiation in sunlight; damage by short-lived reactive oxygen species formed by interactions between ultraviolet radiation, oxygen and hydroxide; trapping in biofilms; sedimentation of particles with attached pathogens; and predation and natural mortality after sedimentation and/or trapping (Jasper et al., 2013; Kadlec and Wallace, 2009). A key limitation of many BMPs is an inability to consistently remove pathogens to relatively low levels required for contact and non-contact recreation in receiving waters (Clary et al., 2008). Additional limitations of BMPs noted by Clary et al. (2008) include high area requirements (e.g., retention ponds), the export of bacteria due to waterfowl and wildlife attraction (e.g., grass swales), high cost and maintenance requirements (e.g., media filters, sand filtration, bioretention cells), and limited data on effectiveness at removing pathogens in stormwater (e.g., porous pavement). A recent review by Jasper et al. (2013) highlights the need to develop natural treatment unit processes optimized to remove pathogens from polluted waters in urban settings.

DeCoursey Pond is an urban pond located in Puyallup, WA. Based on limited water quality data, the pond was identified by state regulators as a probable source of pathogen pollution to nearby Clarks Creek, likely because of high waterfowl density at the pond (Hoffman et al., 2008). The objective of this study was to assess a simple ecotechnology at the pilot-scale to remove pathogens from pond outflow, thereby protecting Clarks Creek from microbial contamination. With an overriding aim for simplicity, this study assessed the effectiveness of rock biofilters – a low-cost ecotechnology consisting of pond water passing over submerged cobbles open to the environment – to remove pathogens from urban pond outflow. Rock filters have been used primarily to remove solids and biochemical oxygen demand from maturation pond effluent, the final step in lagoon treatment of domestic sewage (USEPA, 2002; Mara and Johnson, 2006). There have been few, if any, studies of the use of the simple rock biofilters specifically to remove low levels of indicator organism in surface waters as described in this paper.

2. Materials and methods

2.1. Study site and biofilter system

This study was part of Washington State University's Clarks Creek Water Quality Science, Restoration and Education Implementation Program, an interdisciplinary program funded through the Washington State Department of Ecology to enhance water quality in the Clarks Creek watershed in the South Puget Sound region of Washington. Clarks Creek is a salmon-bearing tributary to the lower Puyallup River, the largest river in South Puget Sound. The creek has a watershed area of 3300 ha and an average flow of 1.7 m^3/s. Clarks Creek is on the Clean Water Act's 303(d) list for FC contamination, and state regulators who are implementing a Total Maximum Daily Load plan have identified DeCoursey Pond as a source of FC to the creek because of its high waterfowl density (Hoffman et al., 2008). This study focused on DeCoursey Pond, a 0.5 ha urban recreational resource in Puyallup, WA. The pond receives inflow from Clarks Creek on its southeast end, and then discharges the water directly back into the creek at its northwest end, which are around 150 m apart. While pond depth and inflow rate, which changes seasonally, are not known precisely, hydraulic residence time in the pond is around a week under typical summertime, moderate-flow conditions.

Fig. 1. Rock biofilter system at the beginning of startup with DeCoursey Pond outlet and Clarks Creek in background. Water was pumped intermittently from the pond to an elevated storage tank (to right) and then discharged continuously by gravity to triplicate biofilters. Water moved from right to left through three cells in each biofilter to an outlet pipe. The black case under the storage tank housed a marine battery used to power a submerged pump at the pond outlet.

The experimental biofilter system consisted of a battery powered submersible pump located near the outlet of DeCoursey Pond. The pump intermittently filled a 130 L container which gravity fed pond water into triplicate biofilter mesocosms (Fig. 1). Water flowed horizontally through the biofilter via gravity to outlet pipes. Each biofilter consisted of a half section of HDPE pipe with a diameter of 0.25 m and a total length of 1.8 m filled with rocks with a diameter of 2–3 cm. Biofilter area was 0.45 m^2 and the active water volume was 15.5 L, or 40% of the total volume. To moderate short circuiting the half sections of pipe were separated into three equal sections with two vertical dividers with surface weirs. Biofilters were loaded with pond water at around 300 mL/min resulting in a hydraulic retention time of around 50 min. Modeling rocks as spheres with an average diameter of 2.5 cm, each biofilter contained an estimated 1800 rocks with a total surface area of 3.7 m^2. Dividing this value by biofilter area (0.45 m^2) yielded a rock surface area per biofilter area of 8.2 m^2/m^2.

2.2. Water quality monitoring

The study assessed removal of two indicator organisms: fecal coliform (FC) and *Escherichia coli* (*E. coli*). FC is a broad class of bacterium, many of which are harmless to humans, and its presence indicates the potential for fecal contamination of a water body. It was monitored because it is the regulated biological contaminant in surface waters (State of Washington, 2011). *E. coli* is a specific fecal coliform found in the fecal matter of warm-blooded mammals, some strains of which are pathogenic. Its presence indicates the potential for pathogen contamination of a water body. *E. coli* was monitored because its fate in the environment may be more representative of actual pathogenic bacteria of fecal origin (Dufour, 1984). In addition, regulatory agencies are expanding surface water standards that include *E. coli*, so assessing both FC and *E. coli* is important relative to future regulatory targets (USEPA, 2012b; Arnone and Walling, 2007). Biofilter inflow and outflow was monitored for FC 1–2 times per month from July through