Ecological Engineering 106 (2017) 482–495

Contents lists available at ScienceDirect

Ecological Engineering

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

The potential of using biological nitrogen removal technique for stormwater treatment

Yewei Sun, Dian Zhang, Zhi-Wu Wang*

Department of Civil and Environmental Engineering, Virginia Tech, Occoquan Laboratory, 9408 Prince William Street, Manassas, VA 20110, USA

ARTICLE INFO

Article history:
Received 17 February 2017
Received in revised form 23 May 2017
Accepted 29 May 2017
Available online 16 June 2017

Keywords:
Stormwater
BNR
Anammox
Nitritation
Biofilms
Alkalinity

ABSTRACT

Biological nitrogen removal (BNR) may provide permanent elimination of nitrogen pollutants by conversion to nitrogen gas. However, few studies have explored the potential of BNR for the removal of nitrogen from stormwater even though this technique has been broadly applied for wastewater purification. Urban runoff is characterized by its low strength and high dissolved oxygen content, which poses multiple challenges to effective BNR. In this study, mathematical modeling indicated that for most runoff input concentrations, complete nitrogen removal within a 0.5-day hydraulic retention time could be achieved if a critical organic carbon concentration is provided in the influent of steady-state bioretention systems. An appropriate amount of organic carbon is required to simultaneously create spatial aerobic and anoxic conditions for successful stormwater BNR in the layered structures of biofilms that are formed on bioretention media and inhabited with syntrophic BNR communities. Because organic carbon is normally limiting in stormwater denitrification processes, anammox becomes an especially important pathway for stormwater BNR. An analysis of influent runoff concentrations from the National Stormwater Quality Database suggested that 71.1% runoff could have nitrogen pollutant removed via partial nitritation followed by anammox. The adequacy of dissolved oxygen, ammonia and alkalinity in stormwater for successful BNR was also evaluated. It was concluded that adjusting influent organic content to a critical value determined in this study should suffice the stormwater BNR requirement of steady-state bioretention systems. Bioaugmentation is required to expedite the bioretention system startup.

Published by Elsevier B.V.

1. Introduction

A large portion of waterways across the world has been identified with excessive nitrogen pollution, a known cause for the water body "dead zone" formation (Dybas, 2005). For example, a study of the Chesapeake Bay showed that increases in reactive nitrogen contributed to excessive growth of phytoplankton, which eventually die, resulting in consumption of available oxygen, and increasing the anoxic and hypoxic waters within the Bay (Galloway et al., 2003). The number of those oxygen-starved "dead zones" has doubled over the past decade and was projected to become the greatest threat to marine ecosystems (Pelley, 2004). Climate change may lead to an increase in nitrogen pollution and a decrease in the time of concentration with the increase of rainfall and thence runoff, which is exacerbated with urbanization (Jennings and Jarnagin, 2002; Makepeace et al., 1995; Davidson et al., 2010). Thus, having a purification technique capable of nitrogen removal from stormwater is imperative in improving water quality of affected surface waters. Out of all existing removal mechanisms, biological nitrogen removal (BNR) is the only one that allows for permanent nitrogen removal, as plant uptake or soil adsorption only temporarily stores and relocates nitrogen pollutants (Valero et al., 2010). BNR transforms nitrogen pollutants into harmless nitrogen gas through bacterial nitrification, denitrification and/or anammox (Cao, 2008). However, the potential of BNR to provide stormwater nitrogen removal is largely unknown, as only limited research on this topic has been conducted. In contrast, much work has been conducted on nitrogen pollutant removal in wastewater treatment. The influent nitrogen concentrations of wastewater are orders of magnitude higher than stormwater. The National Stormwater Quality Database (NSQD) is an urban runoff characterization database developed by Maestre and Morquecho (2005) containing information on runoff water quality for many U.S. sites. As indicated by information summarized from NSQD in Fig. 1a and b (Maestre and Morquecho, 2005), most of the Total Kjehldahl Nitrogen (TKN) and Total Nitrogen (TN) contained in urban stormwater actually falls within very low ranges of 0–2 g TKN m^{-3} (95%) and 1–3 g TN m^{-3} (75%), respectively. It is recognized that even low TN

* Corresponding author.
E-mail address: wzw@vt.edu (Z.-W. Wang).

http://dx.doi.org/10.1016/j.ecoleng.2017.05.045
0925-8574/Published by Elsevier B.V.

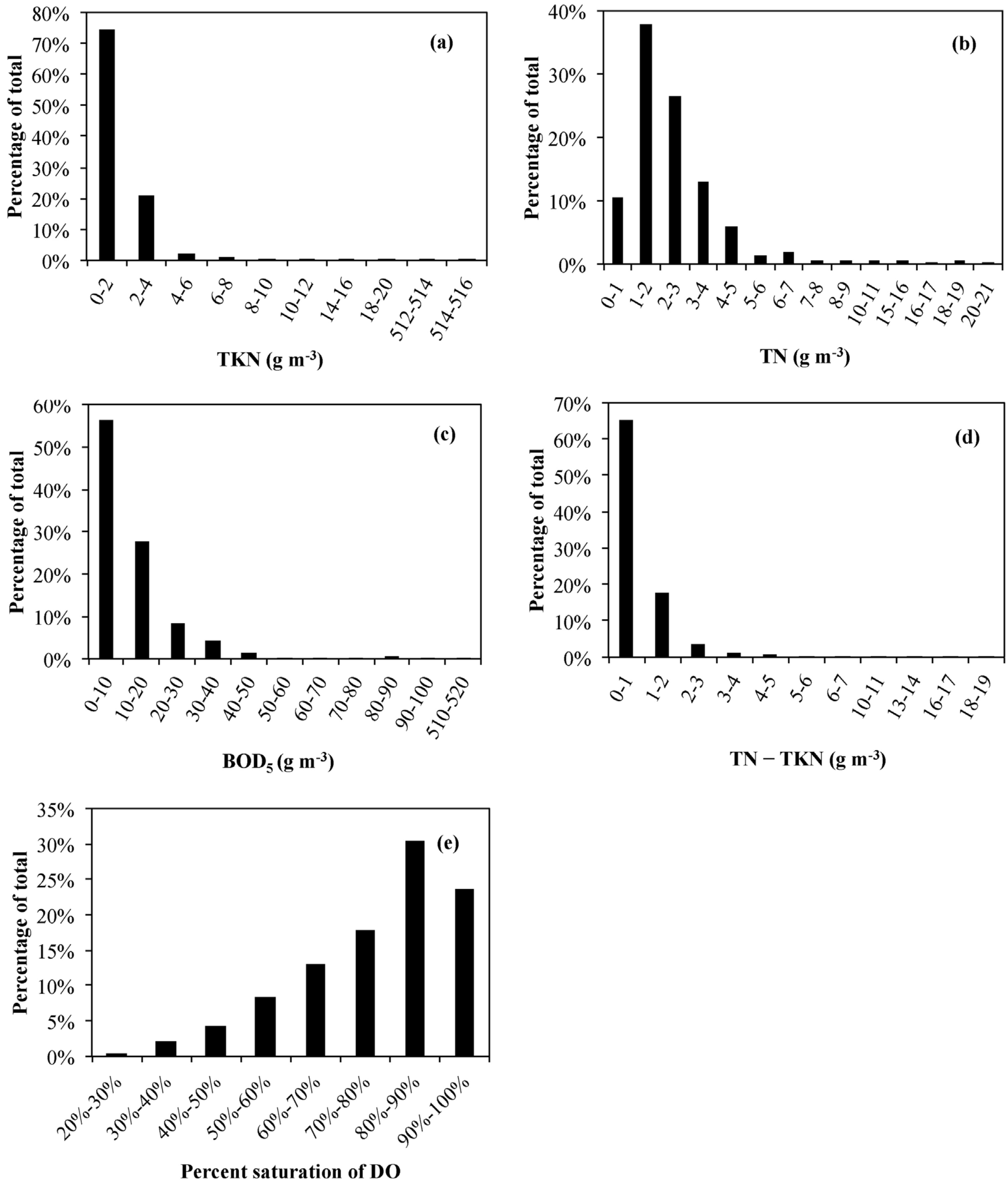

Fig. 1. Probability density of (a) TKN, (b) TN, (c) BOD_5, (d) TKN – TN, and (e) Percent saturation of DO of stormwater reported in NSQD.

concentrations, possibly around 1–2 g N m^{-3}, may trigger eutrophication in nutrient poor (oligotrophic) surface waters (James et al., 2005).

BNR communities usually possess a very high affinity to nitrogen pollutants (half-saturation constant K_s = 0.005–1.1 g N m^{-3} as shown in Table S3 and the study by De Clippeleir et al. (2011)), which enables quick microbial uptake of these pollutants at low concentrations (Hao et al., 1983). However, it is unknown whether BNR communities are able to adapt to the task of stormwater treatment. Mathematical models are a powerful tool that can be used to explore the applicability of BNR. The aim of this study is to provide a thorough and systematic assessment of the potential of BNR for the removal of nitrogen from stormwater using a mathematical modeling approach.

Several members of the BNR microbial communities are extremely slow growing microorganisms, especially in the low strength environment of stormwater. For example, anammox has doubling time of 14–21 days (Strous and Jetten, 2004), in contrast to nitrite-oxidizing bacteria who has doubling time of only 10–13 h (Rodriguez-Sanchez et al., 2014). To sustain those BNR communities with longer retention times but still provide a reasonable processing time for the massive flow of stormwater, system designs that can uncouple solids retention time (SRT) from the hydraulic retention time (HRT) should be considered. Stormwater treatment systems like bioretention (also called biofiltration) immobilize bacterial cells in the form of biofilms in filter media and thus can be used to fulfill this role. As illustrated in Fig. 2, contaminants are removed in bioretention while stormwater passes through the