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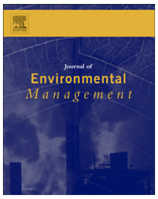

Assessment of the nutrient removal effectiveness of floating treatment wetlands applied to urban retention ponds

Chih-Yu Wang, David J. Sample*

Department of Biological Systems Engineering, Hampton Roads Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University, 1444 Diamond Springs Road, Virginia Beach, VA 23455, USA

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ABSTRACT

The application of floating treatment wetlands (FTWs) in point and non-point source pollution control has received much attention recently. Although the potential of this emerging technology is supported by various studies, quantifying FTW performance in urban retention ponds remains elusive due to significant research gaps. Actual urban retention pond water was utilized in this mesocosm study to evaluate phosphorus and nitrogen removal efficiency of FTWs. Multiple treatments were used to investigate the contribution of each component in the FTW system with a seven-day retention time. The four treatments included a control, floating mat, pickerelweed (*Pontederia cordata* L.), and softstem bulrush (*Schoenoplectus tabernaemontani*). The water samples collected on Day 0 (initial) and 7 were analyzed for total phosphorus (TP), total particulate phosphorus, orthophosphate, total nitrogen (TN), organic nitrogen, ammonia nitrogen, nitrate-nitrite nitrogen, and chlorophyll-*a*. Statistical tests were used to evaluate the differences between the four treatments. The effects of temperature on TP and TN removal rates of the FTWs were described by the modified Arrhenius equation. Our results indicated that all three FTW designs, planted and unplanted floating mats, could significantly improve phosphorus and nitrogen removal efficiency (%, E-TP and E-TN) compared to the control treatment during the growing season, i.e., May through August. The E-TP and E-TN was enhanced by 8.2% and 18.2% in the FTW treatments planted with the pickerelweed and softstem bulrush, respectively. Organic matter decomposition was likely to be the primary contributor of nutrient removal by FTWs in urban retention ponds. Such a mechanism is fostered by microbes within the attached biofilms on the floating mats and plant root surfaces. Among the results of the four treatments, the FTWs planted with pickerelweed had the highest E-TP, and behaved similarly with the other two FTW treatments for nitrogen removal during the growth period. The temperature effects described by the modified Arrhenius equation revealed that pickerelweed is sensitive to temperature and provides considerable phosphorus removal when water temperature is greater than 25 °C. However, the nutrient removal effectiveness of this plant species may be negligible for water temperatures below 15 °C. The study also assessed potential effects of shading from the FTW mats on water temperature, DO, pH, and attached-to-substrate periphyton/vegetation.

1. Introduction

Sustainable, effective, and economical solutions that address water quality degradation problems are actively investigated. Urban non-point source pollution has been identified as a major source of water quality impairments; including excess nutrients, organics, sediment, and metals carried by runoff during storm events (Field, 2006). To properly manage the anthropogenic impacts on natural water bodies, a set of technologies known as best management practices (BMPs) have been developed to treat urban runoff. Constructed wetlands are one of the most commonly used BMPs to improve stormwater quality (Carleton et al., 2001; Wynn and Liehr, 2001). However, land acquisition costs limit the broad application of this BMP (Nduvamana et al., 2007). A relatively new and evolving treatment practice may represent a significant opportunity to retrofit existed stormwater facilities by combining the functions of constructed wetlands and conventional retention (or "wet") ponds. This hybrid system is known as a floating treatment wetland (FTW) (Headley and Tanner, 2012). FTWs use floating mats that sustain and support terrestrial macrophytes and have a wide

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* Corresponding author. Tel.: +1 703 3633835.
E-mail addresses: cywang@vt.edu (C.-Y. Wang), dsample@vt.edu (D.J. Sample).

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range of applicability in water bodies, including retention ponds (Headley and Tanner, 2006; Hubbard, 2010; Zhao et al., 2012).

The combination of FTWs with retention ponds may provide a means to effectively and economically manage urban stormwater quantity and quality. Most urban retention ponds provide flood control, a quantity benefit; whereas, water quality is improved through sedimentation (Shilton, 2005). Conventional methods for improving the pollution control of retention ponds requires continuous chemical or energy inputs, such as flocculants and aeration systems. As a potential supplemental treatment practice, FTWs used in urban retention ponds and associated pollution control mechanisms have been discussed in previous studies (Headley and Tanner, 2012; Van de Moortel et al., 2011; Wang and Sample, 2011). Nutrients and other constituents are absorbed by macrophytes and microorganisms, which grow on the submerged surface of the floating mats and plant roots (Li et al., 2010; Song et al., 2011). Exportation of pollutants from the ponds could be reduced as the constituents are stored in plant tissues and attached microorganisms on the floating mats rather than algae suspended in the water body. A significant portion of biochemical oxygen demand (BOD) and suspended solids in pond effluent is attributed to algae, which is typically flushed downstream during storm events (Shilton, 2005). The surface area provided by the FTWs may address a key limitation of nitrifiers in retention ponds, i.e., the lack of available surface area in aerobic environments, such as the littoral zone of ponds (Zimmo et al., 2004).

Another potential advantage of FTW application is cost. The cost of installing FTWs on conventional ponds could be relatively lower than the cost of land acquisition and construction of new BMPs. In many cases, modification of the ponds is unnecessary unless sedimentation removal is desired. The total cost of an FTW depends mainly upon floating mats and plants and labor for harvesting and planting. Billore et al. (2009) reported that the manufacturing and installation cost of a floating mat was 60 USD/m^2. Costs can be further reduced if recycled materials, such as plastic bottles are used to construct the floating mats (Chen, 2011; Pelton, 2010). Since retention ponds are one of the most widely used BMPs in the US, as reported by the U.S. Environmental Protection Agency, or U.S. EPA (1999), it is possible that a watershed-wide pollutant mass reduction could be economically achieved through FTW application in existing retention ponds. Potential areas of need of this technology may be the contributing urban watersheds of the Chesapeake Bay, an estuary of national importance. The Chesapeake Bay has experienced significant water quality issues; the most significant is a recurring zone of hypoxia which has been attributed to excess sediment and nutrients discharged upstream. Due to the lack of sufficient progress in reducing nutrient and sediment loads to the Chesapeake Bay, the U.S. EPA recently published a Total Maximum Daily Load for the estuary and watershed, requiring significant reductions in nutrient and sediment loads (U.S. EPA., 2010). Treatment technologies such as FTWs, if found to be effective, could assist in meeting these reductions, as they are uniquely suited to removing nutrients from current base loads.

FTWs have been applied to domestic and agricultural wastewater, swine lagoons, and hyper-eutrophic lake waters (Hubbard et al., 2011; Van de Moortel et al., 2010; Wu et al., 2006; Yang et al., 2008). Only a few peer-reviewed studies are available that evaluate the performance of an FTW in an urban stormwater application. We contend that FTW applications in urban retention ponds should address the following concerns. First, stormwater is relatively dilute in comparison with most FTW applications in nutrient-rich waters. The total phosphorus (TP) and total nitrogen (TN) concentrations of runoff from mixed urban land uses typically are 0.26 and 1.8 mg/L, respectively (U.S. EPA, 1999). In comparison, the values for domestic wastewater after secondary treatment are typically 2 and 30 mg/L, respectively (U.S. EPA, 1999). Second, actual urban stormwater has not been widely tested except for three recently published FTW studies. These include two mesocosm experiments and one in-situ test. Winston et al. (2013) monitored inflow and outflow water concentration of two urban retention ponds during storm events. Pre- and post-FTW installation monitoring periods for the same pond were compared and indicated that significant water quality improvement was achieved in the retention pond with 18% coverage. The in-situ experiment reflected the actual behavior of the FTW; however, this approach is necessarily limited by the comparability of the two data sets, which reflect different times. While the inflow concentrations of the pre- and post-FTW installation were found to be statistically similar, the frequency of the loads, the retention time between storm events, and climatic conditions are additional factors that will affect performance, and were not considered in their analysis. In addition, two FTW mesocosm experiments targeted an urban stormwater application (Chang et al., 2012; Tanner and Headley, 2011). In their studies, fertilizers with nutrients were used to create simulated water or provided as supplements in the two urban stormwater FTW studies. A potential disadvantage of this approach is the nutrients are delivered mainly in bioavailable forms such as orthophosphate (Tanner and Headley, 2011). Orthophosphate in fresh water is typically less than ten percent of TP (Wetzel, 2001). These two experiments may reflect the dynamic changes of those readily consumable nutrients; however, removal performance of other forms of nutrients in urban stormwater remains to be addressed. For example, phosphorus in organic forms is processed through biotic decomposition and then absorbed as orthophosphate (Kadlec and Wallace, 2009). Third, two kinds of control are suggested to properly evaluate the compartmental effects of the floating mat and macrophyte on water quality in our pilot experiment. One type of control is water without a floating mat (C); another is a floating mat without plants (M). Presently, only two peer-reviewed studies are available with the two types of control (Hu et al., 2010; Tanner and Headley, 2011). The differences between the M and C indicate the effects of the floating mats. The microorganisms growing on the submerged surface of the floating mats have been suggested as the main pollutant removal mechanism of FTWs (Headley and Tanner, 2006; Wen and Recknagel, 2002). Shading caused by floating mats may alter other ongoing processes within the water body, such as photosynthesis. These floating mat effects were largely ignored when only one type of the control, C or M, was utilized in the experiments. The differences between planted and unplanted floating mats represent the performance of the macrophytes and associated microorganism. The surface area of the root systems serves as habitats of microorganisms (Nduvamana et al., 2007; Osem et al., 2007). Although nutrient uptake by macrophytes could be estimated through analyses of harvested plant tissue (Hubbard et al., 2011; Wen and Recknagel, 2002; Zhu et al., 2011), it may not include the contribution of the attached biofilms. Additionally, variation of parameters, such as DO and pH, could be caused by shading of the floating mats, plant activities, or both. Without an M control, it is impossible to reliably estimate these effects. Last, effectiveness of FTWs, while reported by many, has not been subjected to a rigorous statistical analysis except a few papers (Van de Moortel et al., 2010; Yang et al., 2008). These results may generate misleading conclusions if the assumptions of the underlying statistical analysis methods are not fully satisfied.

The objective of our study is to evaluate FTW performance in urban retention ponds where water was mostly supplied from runoff during storm events. Our hypotheses are: 1) FTWs can effectively enhance nutrient removal when compared to the control; 2) FTW removal is temperature dependent; 3) nutrient