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Attenuation of pharmaceuticals, nutrients and toxicity in a rural sewage lagoon system integrated with a subsurface filtration technology

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HIGHLIGHTS

- Performance of this full-scale system is similar to a previously studied pilot-scale system.
- No apparent effect of acclimation of the filter was observed for studied parameters.
- Most detected pharmaceuticals were removed from wastewater during lagoon treatment.
- Carbamazepine and sulfamethoxazole persisted after subsurface filtration.
- Detected contaminants do not pose an acute risk for aquatic species in receiving environment.

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ABSTRACT

Although many studies have addressed the ability of subsurface filtration systems to remove emerging contaminants from wastewater at micro- and mesocosm-scale, little is known about their performance on full-scale wastewater treatment facilities. To understand better how effective these systems can be for municipal wastewater polishing, we assessed the ability of a full-scale lagoon-subsurface filter system located in Dunnottar, Manitoba, Canada, to attenuate regulatory wastewater parameters, nutrients, pharmaceuticals, and toxicity over the course of the discharge periods in 2015 and 2016 (June–October). Pharmaceuticals included β-blockers, anticonvulsant drugs, and macrolide and sulfonamide antibiotics. Out of six consistently detected pharmaceuticals, four were efficiently removed through lagoon treatment (e.g. clarithromycin, metoprolol, propranolol), while two persisted to a certain extent (e.g. carbamazepine, sulfamethoxazole), even after subsurface filtration. Attenuation was observed for nutrients with averages of 40% and 60% for ammonia and total phosphorus respectively within the filter, consistent with previous pilot-scale studies at this facility. Compliance with regulations for conventional wastewater parameters at the effluent was observed, as well as reduced acute toxicity (as determined by Microtox®) from the primary lagoon to the effluent, and little likelihood of acute toxicity in receiving waters. Our results suggest that first, the full-scale system has an overall similar performance when compared to the previously studied pilot-scale system; second, there was no apparent effect of acclimation on the attenuation of studied contaminants or toxicity; and finally, the concentrations of contaminants do not appear to pose an acute risk for aquatic species in the receiving environment.

1. Introduction

The occurrence of contaminants in wastewater can represent a hazard to aquatic ecosystems and a challenge for wastewater

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treatment systems worldwide (Kolpin et al., 2002). More than 200 pharmaceutical active ingredients are found in aquatic compartments in concentrations ranging from a few nanograms per liter to thousands of micrograms per liter (Hughes et al., 2013). Excess nutrients (e.g. phosphorus and nitrogen) are also a concern in wastewater due to their promotion of eutrophication. To address the hazards that these contaminants pose to receiving environments, an improvement in current wastewater treatment practices is needed, along with a greater understanding of removal mechanisms. Wastewater lagoons are commonly used in rural North America for sewage treatment. They are bodies of water designed to hold and perform some treatment of wastewater for a defined amount of time and are typically far less costly than conventional activated sludge wastewater treatment. Thus, they are common in smaller communities with limited infrastructure and resources in North America (Lishman et al., 2006; Conkle et al., 2008; Chaves-Barquero et al., 2016). The implementation of lagoons occurred before a stricter regulatory environment emerged around wastewater discharges (Smith, 2003). Wastewater guidelines for contaminants have recently been published, for example the Canada-wide strategy for the Management of Municipal Wastewater Effluent, which aims to implement a strategy to develop a targeted research program that will encompass emerging substances, such as organochlorine pesticides, polychlorinated biphenyls, polyaromatic hydrocarbons as well as pharmaceuticals and other personal care products (CCME, 2014). In Canada, regulations are becoming more stringent for BOD, P, and total suspended solids (TSS). In Manitoba, where this research takes place, maximum levels have been fixed to 25 mg L^{-1} for BOD and TSS (CCME, 2014), and 1 mg L^{-1} for total phosphorus (Manitoba Water Stewardship, 2011).

Constructed wetlands can provide a low-cost alternative for wastewater treatment in regions where availability of land is not a limiting issue. Nevertheless, no specific guidelines have been established for designing full-scale systems to remove pharmaceutical compounds from wastewater. Furthermore, attenuation of wastewater organic contaminants can be limited on these systems, depending on hydraulic loading (Zhang et al., 2012). There are knowledge gaps related to the performance and design of these systems for the attenuation of pharmaceuticals and other organic contaminants in municipal wastewater, especially at pilot and full-scale facilities, where comprehensive evidence could be gathered in comparison to laboratory and mesocosm-scale experiments, which have been more frequently conducted in the literature (Li et al., 2014).

To address some of the treatment challenges described above, a pilot-scale subsurface filtration system was built in 2009 at the Village of Dunnottar, Manitoba, Canada, near the shore of Lake Winnipeg (the 10th largest freshwater lake in the world by surface area). The main purpose of this system was to reduce the release of traditional wastewater contaminants (e.g. phosphorus, coliforms) and its efficiency in this area has been previously reported (Anderson et al., 2015). The pilot-scale filter showed significant attenuation for nutrient loadings, such as phosphorus and nitrogen, but limited to no removal of most organic contaminants (e.g. pharmaceuticals), likely due to the short residence time of the wastewater in the filter bed (~6 h). This system served as a model for the construction of a full-scale filter at Dunnottar in 2014. It commenced operations in June 2015 with the purpose of achieving the same level of wastewater treatment. The full-scale system was not expressly designed to remove or attenuate organic contaminants (e.g. pharmaceuticals, personal care products). Nevertheless, due to its design, it offered a valuable opportunity to study the concentrations of organic contaminants along the wastewater path with the aim of understanding the fate of these substances at all stages of the treatment. Such a system could be implemented as a model for similar rural communities as a low-cost, low-maintenance method to perform municipal wastewater treatment under current regulatory compliance. At the same time, it would serve as a platform for manipulation studies that help understand the effect of several design parameters on the potential attenuation and removal of emerging contaminants, should it be occurring.

In this study, we were interested in first, assessing the removal efficiency of the current full-scale wastewater treatment system at Dunnottar, Manitoba for pharmaceutical residues, phosphorus and toxicity; second, characterizing possible toxicological impacts on the surrounding aquatic environment from the release of wastewater; and third, comparing the full-scale system's performance over time (2 years) and with the pilot-scale system. We hypothesize that first, the full-scale treatment system will perform more efficiently than the pilot-scale system in attenuating wastewater contaminants of interest and toxicity due to larger scale and increased hydraulic retention time; second, detected contaminants will not pose a significant risk to the surrounding aquatic environment; and third, acclimation of the system will result in performance improvements during the second year of operations. This study will inform the design and management of subsurface treatment systems with similar characteristics in North America and around the globe.

2. Experimental

2.1. Study location

The municipal wastewater treatment system at Dunnottar consists of an array of three lagoons (Fig. 1) providing services for the Village of Dunnottar and the Provincial Park Camp Ground in Winnipeg Beach. The village has approximately 763 permanent residents, though summer season use from vacationers increases its population several-fold (Anderson et al., 2015). Residential holding tanks have been installed in the community, and sewage is hauled continuously and discharged in the primary lagoon using septic trucks.

In 2009, a four-cell pilot-scale subsurface passive filter was installed with the aim of further polishing the wastewater after lagoon treatment. Based on this pilot-scale design, a two-cell full-scale subsurface filtration system was built (Fig. 1). Each of these cells is 50 m long × 25 m wide × 1.2 m deep for a total array volume of 3000 m^3 (Fig. 2), and can treat wastewater at a maximum rate of 500 m^3 d^{-1} (average ~265 m^3 d^{-1}). An intake well collects wastewater from the secondary lagoon and pumps it vertically into the filter bed through a distribution pipe. Wastewater is then redirected into an outflow well from where it is pumped through an inline Trojan UV 3000 PTP ultraviolet treatment system, the output of which flows into Tegula creek for 1.5 km to Lake Winnipeg. Hydraulic retention time (HRT) can reach a maximum of 86 h (average ~45 h). No chemical inputs (e.g. coagulants, flocculants, conditioners) were performed during the operation of this wastewater treatment facility in either 2015 or 2016.

2.2. Sample collection

In 2015 and 2016, water quality parameters (BOD, COD, total phosphorus, total suspended solids, total and fecal coliforms) in the final effluent were taken by the Village of Dunnottar in collaboration with Dillon Engineering Ltd. and measured by standard methods (APHA, 2005) at ALS Environmental. Sites chosen for pharmaceuticals and toxicity sample collection were: ~15 m away from the sewage discharge point in the primary lagoon ("primary lagoon"), at the former entry point into the pilot-scale filter from