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Physical and biological changes of suspended particles in a free surface flow constructed wetland

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ABSTRACT

Suspended particles are considered as contaminants in treated wastewater and can have profound effects on the biological, physical and chemical properties of receiving aquatic ecosystems, depending on the concentration, type and nature of the suspended particles. Constructed wetlands are known to substantially reduce the concentration of suspended particles in treated wastewater, but hardly anything is known about the changes in the type and nature of these particles. Therefore, the aim of the present study was to investigate the changes in the physical and biological characteristics of suspended particles during residence in the full scale surface flow constructed wetland. The constructed wetland consists of unvegetated ponds and reed beds and receives treated municipal wastewater containing low concentrations of suspended particles. It was found that residence in the unvegetated ponds caused no major changes in particle concentration, but the organic content (53–33%) and average size (4.3–3.7 μm) of the suspended particles did decrease, caused by sedimentation of large organic particles and addition of smaller inorganic particles most likely resulting from shore erosion. The bacterial species originating from the wastewater treatment plant (quantified by indicator organisms) decreased strongly in abundance (>90% reduction), especially during residence in the reed beds. Simultaneously the total abundance of bacteria gradually increased, indicating the replacement of the bacterial species present in the treated wastewater with other species during residence in the constructed wetland. These observations indicate that constructed wetlands change the nature and type of the suspended particles during residence in a constructed wetland and reduce the input of anthropogenic particles into receiving surface waters.

1. Introduction

Suspended matter is defined as the filterable matter in the water column and consists of particles of highly variable type and origin (Wotton, 1994). Suspended matter is involved in many biological, physical and chemical processes in aquatic ecosystems, like primary production, decomposition, nutrient cycling, energy transfer, contaminant binding, oxygen regulation, light absorption and temperature regulation (Noe et al., 2007; Bilotta and Brazier, 2008; Olsen et al., 1982; Dawson and Macklin, 1998; Russell et al., 1998; Wetzel, 2006; Droppo et al., 1997). The role of suspended matter in this complex set of processes depends on the concentration, nature and type of the suspended particles. In turn, the concentration and type of suspended matter is influenced by both internal processes such as sedimentation, resuspension, aggregation, disaggregation, decomposition, biomass growth, cell lysis and biofiltration, and external processes such as atmospheric deposition, shore erosion, chemical precipitation and land runoff (Wotton, 1994; Zufall et al., 1998).

Municipal wastewater is a common anthropogenic source of suspended particles into aquatic ecosystems. Although regular treatment of domestic wastewater strongly reduces the concentration of suspended particles (Tchobanoglous et al., 2004), suspended particles present in treated domestic wastewater still lead to alterations of the physical, biological and chemical properties of receiving aquatic ecosystems (Holeton et al., 2011; Bilotta and Brazier, 2008; Tchobanoglous et al., 2004). Wetlands are known to reduce the suspended particles concentration (Kadlec and Wallace,

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2008; Knox et al., 2008) and constructed wetlands (CWs) are widely used for polishing (treated) municipal wastewater and thereby reduce the discharge of anthropological particles into surface waters (Kadlec and Wallace, 2008; Vymazal, 2005; Mungasavalli and Viraraghavan, 2006; Sundaravadivel and Vigneswaran, 2001). Although many physical and biological processes maybe involved, suspended particle removal in constructed wetlands is primarily ascribed to sedimentation (Kadlec and Wallace, 2008). Consequently surface flow CWs receiving higher inflow concentrations generally show substantial removal of suspended particles up to 90% (Ghermandi et al., 2007; Van den Boomen et al., 2012; Van den Boomen and Kampf, 2012). However, CWs with low inflow concentrations of particles (background levels) have been observed to produce equal or slightly increased outflow concentrations (Ghermandi et al., 2007; Van den Boomen and Kampf, 2012). It is apparent that inflow concentrations strongly influence the removal efficiency of suspended particles by constructed wetlands (Ghermandi et al., 2007; Kadlec and Wallace, 2008) and the observed inefficient particles under low particle inflow conditions raises questions on the usefulness of constructed wetlands for polishing well treated (low particle concentrations) wastewater. However, without net reduction of particle concentrations surface flow constructed wetlands are still likely to affect the composition and nature of particles.

As the large majority of research on particles in constructed wetlands in mostly concentrated on bulk concentration measurements, a detailed analysis of changes in particle composition is difficult from existing data. Therefore the present study investigated biological and physical changes in the concentration, nature and type of particles present in treated wastewater during residence in a full scale surface flow CW receiving well treated domestic wastewater. We conducted this research in a CW receiving low suspended particle inflow concentrations to ensure that strong particle removal by sedimentation would not overshadow the effect of other processes affecting particles in constructed wetlands. To analyse the suspended particle concentrations and functioning of the constructed wetland, suspended particles concentrations faecal indicator organism numbers, and physicochemical parameters were extensively monitored on a period of five years. To gain more insights into the into suspended particle dynamics intensive short term monitoring campaigns were conducted focusing on particle size distribution, organic content, dissolved element concentrations, sedimentation, biota abundance and microscopy imaging.

2. Material and methods

2.1. Study area

This study was carried out in a full scale surface flow constructed wetland (CW) located in Grou, The Netherlands. The CW was built in 2006 and receives treated municipal wastewater with a constant hydraulic load (1200 m^3 day^{-1}). The inflow of the constructed wetland leads treated wastewater through a series of three unvegetated ponds and four parallel reed beds, before being pumped into receiving surface water (channel) (Fig. 1, Table 1).

The unvegetated ponds are open water systems with an average depth of 1.35 m, width of ±7.9 m, length of 55 m, volume between 360 and 440 m^3 each and total hydraulic residence time (HRT) of 17.9 h (Fig. 1). The reed beds are covered with *Phragmites australis* and have an average water depth of 0.4 m, width of ±11 m, length of 110 m, approximate volume of 443 m^3 each and each receives a hydraulic load of ±300 m^3 day^{-1} with an average HRT of 23.6 h. The total HRT of the CW was 41.5 h. Hydraulic residence times were calculated from the residence time distribution obtained by a tracer experiment using lithium chloride, performed in 2010. The average hydraulic residence time was determined at 50% passage of the lithium chloride load (Van den Boomen et al., 2012).

2.2. Five year monitoring

Monitoring of the CW was conducted over a five year period from 2007 until 2011 and included analyses of suspended particles, *Escherichia coli* and physicochemical parameters. The sample frequency was mostly monthly, but varied between sampling locations and in time over the five year period. Samples were taken at three sampling points, at the in- and out-flow of the unvegetated ponds and at the out-flow of the reed beds (respectively PONDS-IN; PONDS-OUT; REED-BEDS-OUT). Samples were taken as point samples 0.2 m below the water surface at the middle of the water body using a 10 L vessel. Subsamples were taken for individual analyses and stored at 4 °C prior to further analyses initiated within 24 h. Suspended particle concentrations were determined by filtration (GF-F; Ø47 mm, pore size 0.7 μm) and sequential drying and weighing of the filters according to standard methods (NEN-EN-872, 2005). Samples that were below the detection limit of 0.5 mg L^{-1} were included in further analyses with a value of halve the detection limit (0.25 mg L^{-1}). *E. coli* concentrations were determined by membrane filtration according to standard methods (NEN-EN-ISO-9308-1, 2000). pH and dissolved oxygen were measured in situ according to standard methods NEN-ISO-10523 (2008) and NEN-EN-ISO-5814 (1993), respectively.

2.3. Particle characteristics and composition

In the period of 2009 till 2011 three short term sampling campaigns (1–14 days) were conducted to quantify inorganic and organic content of suspended particles, suspended particle size distribution, bacteria, eukaryote, *Enterococci* and *Clostridium perfringens* abundance.

Microscopic observations of suspended particles water samples (50 mL) were taken at the three sampling points in the CW and fixed with 37% formaldehyde (10%, v/v). After fixation halve of the samples were filtered over 0.2 μm polycarbonate filters (Ø47 mm; Sartorius Stedim Biotech, Göttingen, Germany) and stored at −20 °C till further analyses with environmental scanning electron microscopy (ESEM). The other halve of the samples were not filtered and stored at 4 °C till analysed with light microscopy. Filters were analysed by ESEM under semi vacuum conditions (Hitachi TM3000, Tokyo, Japan) at a magnification of 500×. The unfiltrated samples were left for particle settling at least 24 h before observation with an inverse light microscope. Settled material was transferred onto microscope slide and pictures of the particles were taken at a magnification of 500×.

The inorganic fractions were calculated after ignition (550 °C) of filtered and dried suspended particles, according to standard methods (NEN-6499, 2005). The organic content was converted to carbon content (mg C L^{-1}) by assuming a carbon content in organic matter of 58% (Schulte and Hopkins, 1996). Suspended particle size distributions (2.0 and 100 μm) were analysed in 20 mL water samples using a particle counter (PAMAS Waterviewer; PAMAS GmbH, Rutesheim, Germany; sensor: HCB-50/50). Analyses of the particle size distribution were conducted within one hour after sampling and stored at room temperature prior to analyses.

For determination of the eukaryotes and bacteria abundance, water samples (50 mL) were fixated with 37% formaldehyde (10%, v/v) and subsequently filtered over 0.2 μm polycarbonate filters (Ø47 mm; Sartorius Stedim Biotech, Göttingen, Germany) and stored at −20 °C prior to further analyses. Using fluorescence in situ hybridisation according to Glockner et al. (1996)