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Long-term hydraulic and treatment performance of a 19-year old constructed stormwater wetland—Finally maturated or in need of maintenance?

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ABSTRACT

Constructed stormwater wetlands (CSWs) are a commonly used measure for stormwater retention and quality treatment. However, although questions have been raised about the long-term performance of CSWs, only a few studies have targeted this issue and none have evaluated the performance of CSWs more than approximately 5–10 years old. Further, most studies have not examined the development of the long-term performance of CSWs but delivered a snapshot at a certain point of time. The present study investigated the performance of a 19-year-old CSW in Växjö, Sweden, treating stormwater from a 320-ha urban catchment. Besides removal of sediment from the CSW's forebay, no other maintenance had been conducted. However, regular inspections had been performed. The results of the present sampling campaign were compared to two existing datasets collected at the same CSW after three years of operation in 1997 and nine years of operation in 2003. The CSW was found to provide efficient peak flow reduction and, depending on the event characteristics, also volume reduction. It still treated stormwater effectively: removal of Cd, Cu, Pb, Zn, TSS and TP event mean concentrations were between 89 and 96%, whereas mean concentrations of TN were reduced by 59%. The load removal efficiencies were even higher. Comparative analysis of the three monitoring periods based on the load removal efficiency revealed that the CSW, despite the lack of maintenance, performed more efficiently and stably for most pollutants compared to when newly constructed. This underlines the importance of the establishment and maturation of constructed wetland systems. Overall, the results showed that CSWs are resilient systems, which if designed well and regularly inspected to prevent major issues, can work efficiently for at least two decades.
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1. Introduction

Since urban stormwater runoff often contains significant amounts of pollutants (e.g. sediments, nutrients, heavy metals), it has been recognized as a major pollution source causing degradation of the receiving water body's quality (US EPA, 2000). Furthermore, the discharge of high peak flows and large volumes of stormwater runoff into the receiving water without retention may cause (*inter alia*) flooding, high flows and erosion in the receiving water body (Ellis and Marsalek, 1996; Walsh, 2000).

To address these issues, there has been increasing interest in using various stormwater control measures (SCMs) to mitigate these negative effects. Among other SCMs, constructed stormwater wetlands (CSWs), often combined with a pre-treatment sedimentation pond or forebay, have gained popularity in Sweden and worldwide for urban stormwater management. There have been numerous studies demonstrating that CSWs have the ability to effectively remove pollutants from urban stormwater runoff (Revitt et al., 1999; Bulc and Slak, 2003; Terzakis et al., 2008; Wadzuk and Traver, 2008; Knox et al., 2010), attenuate peak flows and discharge volumes (Martin and Smoot, 1986; Martin, 1988; Ellis and Marsalek, 1996; Scholes et al., 1998; Walker and Hurl, 2002; Hunt and Lord, 2006; Li et al. 2010) and, more recently, deliver ecosystem

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services (e.g. wildlife habitat, recreation area; Brydon et al., 2006; Greenway, 2010).

However, most of the aforementioned studies were restricted to a short-term perspective, and thus the long-term performance of CSWs and development of their treatment performance over time are still largely unknown. So far, only a few studies have dealt with the long-term function of treatment wetlands (exceeding 10 years) focussing exclusively on wastewater treatment wetlands (e.g. Vymazal, 2011). In addition, the effect of inspection and maintenance measures or deficits on their performance needs to be considered (Blecken et al. in press). Chen (2011) and Martin (1988) reported that accumulation of retained pollutants in CSW systems not subjected to regular maintenance measures may affect the effectiveness of the system, especially when receiving high discharges of stormwater runoff. Furthermore, maintenance of vegetation also plays an important role, not only with regard to water treatment quality but also habitat value (Chen, 2011). The loss of vegetation due to maintenance/inspection deficits has been described by Hunt et al. (2011). Furthermore, regular maintenance is required to remove and clean-up sediments, debris and weeds as well as trim vegetation to allow CSWs to effectively remove pollutants and reduce stormwater peak flows and discharge volumes (Hunt and Lord, 2006). Regular maintenance of forebays is also essential, particularly the removal of accumulated sediment to avoid re-suspension. On the other hand, in CSWs, the multiple geochemical and biological processes incorporated for pollutant treatment may benefit more from maturation of the wetland (mainly due to vegetation establishment and associated processes) than from extensive maintenance (which may also lead to disturbance of the system). Thus, further long-term studies to assess the performance of established SCMs (including CSWs) and their development are demanded by both researchers and practitioners (D'Arcy and Sieker, 2015; Blecken et al. in press).

The objective of this study was to assess the removal efficiency of TSS, heavy metals (Cd, Cu, Pb and Zn) and nutrients (total nitrogen and total phosphorus) in a 19-year-old CSW in Växjö, Sweden based on the reduction of pollutant event mean concentrations (EMCs) between the inlet and outlet and pollutant load removal efficiency. To investigate the development of the long-term performance of this CSW, the results obtained in this study (conducted in 2013/14) were compared with two existing datasets collected at the same CSW after the first three years of operation after its construction in 1994 (Växjö Municipality, 1998) and after nine years of operation in 2003 (Semadeni-Davies, 2006). This enabled analysis of a unique time series of the CSW's function, in contrast to most previous studies that only delivered "snap-shots" at a certain point of time. Since this system had not been maintained (except from sediment removal from the forebay) since its construction in 1994, we were able to evaluate whether this maintenance deficit had any impact on the CSW's treatment performance.

2. Materials and methods

2.1. Site location and description

The Bäckaslöv CSW investigated in this study was constructed in 1994 and located in Växjö, southern Sweden (56°52′25.0″N, 14°47′00.8″E; Fig. 1). Inner Växjö is surrounded by lakes that function as receiving water bodies for stormwater from the city. As a result of untreated stormwater discharge (*inter alia*), the water quality of these lakes was seriously impaired in the 1970s to 1990s, mainly due to eutrophication (Växjö Municipality, 1998). The main goal of the construction of the Bäckaslöv CSW was to reduce pollution export to Lake Södra Bergundasjön, and thus improve its water quality. Before the construction of the CSW, a ditch conveyed the stormwater runoff to the lake without treatment. Since 1994, the CSW has served as the main treatment facility for stormwater from a 320 ha catchment (130 ha residential area, 190 ha industrial/commercial area and several major roads), as well as a recreational area and bird habitat as part of a large nature reserve.

The CSW system consists of a sedimentation pond with a water surface of 1.8 ha and average depth of 1.6 m followed by a 5 ha meandering wetland stream (appr. 800 m long). The ratio of the CSW area to the catchment area is 2%. The pond receives stormwater through two inlet culverts of 1400 mm diameter. The pond was designed to accommodate a 2-year storm event and receives a base flow of 2500 m^3 day^{-1} (i.e. approx. 104 m^3 h^{-1}). The measured baseflow in 2013/14 (see below) was slightly higher (126 ± 18 m^3 h^{-1}). The pond is divided into two parts connected by a bridged channel as an access road. The first minor part of the pond serves as a coarse sediment forebay. The second part of the pond includes an island that distributes the flow more evenly in the pond and serves as a bird habitat. From the pond, the stormwater is conveyed into the wetland via two culverts of 550 mm, each accommodating a maximum flow of 200 l/s. An overflow weir allows excess flow to discharge through a bypass pipe into the wetland. The outflow from the CSW is controlled by a weir, and then taken to Lake Södra Bergundasjön via a stream. During the 19-years of operation, the CSW and the second part of the pond were not maintained at all. However, sediment from the first part of the pond was dredged four times and stored in the vicinity of the system.

The average annual precipitation in Växjö is 652.6 mm, and the temperature typically varies from −6 °C to 23 °C over the course of a year (Alexandersson et al., 1991). During the winter season, deicing and anti-slipping materials (fine macadam (0–8 mm) mixed with road salt (50 g/m^3)) are regularly applied to the streets. After the snowmelt period, these materials are removed by a mechanical sweeper.

2.2. Monitoring periods

To investigate the long-term development of the CSW pollutant removal, two sets of water quality measurements from the same CSW were obtained from previous studies (Johansson, 1997; Växjö Municipality, 1998; Semadeni-Davies, 2006). The first sampling campaign was conducted by Växjö Municipality during summer 1997 (Johansson, 1997; Växjö Municipality, 1998) and the second campaign was performed by Semadeni-Davies (2006) during winter – spring 2003. Our study covered the period from May 2013 to April 2014. Thus, data collected at the same facility between 1997 and 2014 could be compared. Stormwater quality and quantity measurements in the CSW were carried out during these monitoring periods.

2.2.1. Monitoring period 2013–2014

In the present study, the same sampling stations (P1, P2, and P3; Fig. 1) as used in the two previous studies were used to enable comparison of the results (Johansson, 1997; Semadeni-Davies, 2006). Continuous flow monitoring and water quality sampling were conducted. Mainstream™ Premier Fixed AV flow meters were installed at P1 and P2 to measure water flow in the pipes, whereas a MJK 713 flow meter was installed at P3. Rainfall depth and intensity were measured using an Adcon Professional Rain Gauge with 0.2 mm resolution sited close to P1. At each sampling station, all data were logged and transmitted using an A753 addWAVE GSM/GPRS. The stations were each equipped with three automatic samplers (ISCO Avalanche Portable Refrigerated Samplers at P1 and P3, ISCO 6712 Portable Sampler at P2), which were programmed to collect flow-weighted composite samples during storm events. The automatic samplers at P1, P2, and P3 were triggered to take samples when

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