Ecological Engineering 98 (2017) 307–317

Contents lists available at ScienceDirect

Ecological Engineering

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

Seasonal variation in nutrient removal efficiency of a boreal wetland detected by high-frequency on-line monitoring

P. Valkama[a,*], E. Mäkinen[b], A. Ojala[c], H. Vahtera[a], K. Lahti[a], K. Rantakokko[b], H. Vasander[c], E. Nikinmaa[c], O. Wahlroos[c]

[a] Water Protection Association of the River Vantaa and Helsinki Region, Asemapäällikönkatu 12 B, 00520 Helsinki, Finland
[b] Environment and Natural Resources, Centre for Economic Development, Transport and the Environment for Uusimaa, P.O. Box 36, 00521 Helsinki, Finland
[c] Department of Forest Sciences, University of Helsinki, P.O. Box 27, 00014 Helsinki, Finland

ARTICLE INFO

Article history:
Received 31 January 2016
Received in revised form 11 October 2016
Accepted 13 October 2016
Available online 28 October 2016

Keywords:
Wetland
Water quality
Total phosphorus
Nitrate-nitrogen
High-frequency monitoring

ABSTRACT

Wetlands play an important role in reducing nutrient loads to receiving waters. The efficiency of a wetland in nutrient removal is commonly evaluated from discrete water samples taken at the inflow and at the outflow of the target wetland. In order to reveal variation in removal efficiency we carried out one year of high-frequency monitoring (HFM) of water quality and quantity at a wetland established at the mouth of an urban/agricultural watershed in boreal southern Finland. Data collected at the inflow and outflow of the 0,5 ha wetland was used to determine the range of total phosphorus (TP) and nitrate nitrogen (NO_3–N) concentrations. The incoming and outgoing TP and NO_3–N loads were calculated and the relative and absolute reduction rates were determined. The wetland received 24 g P m^{-2} $year^{-1}$ and 130 g NO_3–N m^{-2} $year^{-1}$ and it retained 3.1 g m^{-2} $year^{-1}$ of P and 18 g m^{-2} $year^{-1}$ of NO_3–N. Annual TP reduction was 13% and NO_3–N reduction 14%. The relative removal efficiency of TP was found to be dependent on retention time and NO_3–N removal efficiency was dependent on temperature, oxygen concentration, NO_3–N concentration and discharge.

1. Introduction

Eutrophication caused by excessive amounts of the main nutrients phosphorus (P) and nitrogen (N) discharged into lakes and sea areas is considered to be a worldwide environmental problem causing e.g. large scale hypoxia/anoxia in affected areas of the Gulf of Mexico and the Baltic Sea (Diaz, 2001; Bechmann et al., 2008; Kronvang et al., 2009). While point sources of nutrients have been effectively decreased, for example by the establishment of wastewater treatment plants, managing nutrient supply from non-point sources has gained an increasingly important role in reducing eutrophication. Especially agricultural activities have contributed to non-point source nutrient load to receiving waters (Withers et al., 2014). To diminish this load several different measures such as vegetated agricultural drainage ditches, gypsum application to agricultural fields and/or buffer zones have been introduced and their impact on nutrient removal has been studied (Syversen, 2005; Moore et al., 2010; Ekholm et al., 2012).

There is a need for efficient measures to reduce nutrient loads to the Baltic Sea suffering from eutrophication and resulting cyanobacterial blooms as well as extended hypoxia and anoxia (HELCOM, 2014). Wetlands have been introduced as an efficient method to reduce diffuse nutrient loads and thus prevent eutrophication in various climate conditions (Fisher and Acreman, 2004; Braskerud et al., 2005; Hansson et al., 2005; Land et al., 2016). The efficiency of wetlands to retain nutrients has been linked to the ratio between size of the wetland and the size of the contributing catchment (Wilcock et al., 2012). If the size of the wetland is large in relation to the catchment, then the relative nutrient retention is expected to be high. This is due to the impact of hydraulic load which has an effect on the amount of water and the nutrient load that enters the wetland (Kadlec and Knight, 1995; Braskerud, 2002).

Many investigations of nutrient removal efficiency by wetlands have been based on discrete water samples taken at the inflow and the outflow of a given study wetland (Vohla et al., 2007; Lu et al., 2009; Dias and Baptista, 2015). However, the sporadic sampling may lead to large inaccuracy in load calculations as shown with streams and rivers (Jones et al., 2011; Skarbøvik et al., 2012). This is because the changes in water quality and quantity can be very rapid especially in small catchments and thus majority of annual nutrient loads may be transported during relatively short-term flow periods

---

* Corresponding author.
E-mail address: pasi.valkama@vesiensuojelu.fi (P. Valkama).

http://dx.doi.org/10.1016/j.ecoleng.2016.10.071

(Langlois et al., 2005; Gao et al., 2007; Drewry et al., 2009). The bulk of non-point source loads from the catchments in boreal environment typically occurs outside the growing season during snowmelt period in spring and during rainy period in autumn (Puustinen et al., 2007; Bechmann et al., 2008). Consequently the load calculations based on low sampling frequency will more likely lead to too small load estimations as highest load peaks are easily missed (Valkama and Ruth, 2016). Thus there is a clear need to investigate the functioning and nutrient removal efficiency of boreal wetlands, receiving highly fluctuating in quality and quantity waters, with high frequency monitoring (HFM).

High frequency monitoring data presented in this paper was collected from January 2014 through December 2014 covering a full calendar year. Monitoring was conducted at the inflow and the outflow of a study wetland in order to quantify nutrient mitigation success by this wetland. The wetland forms a buffer between a eutrophicated lake and a stream catchment polluted by agriculture and stormwater from an agricultural and an urban subcatchment respectively (Fig. 1). The wetland's water quality has been monitored as a part of a wide scope EC Life+ Urban Oases project. The monitoring results for water, vegetation and fauna from the projectís preceding year 2013 referenced in this paper can be found in Wahlroos et al. (2015). In this present paper we focused on seasonal variation in nutrient treatment efficiency of the project wetland Gateway.

The aims of the presented study were to:

1) Evaluate the efficiency of the study wetland in TP and NO_3–N removal using high frequency water quality monitoring,
2) Study daily and seasonal variation in relative and absolute reduction rates of TP and NO_3–N by the study wetland.
3) Investigate which factors affect treatment performance of the study wetland.
4) Demonstrate the benefit of HFM in wetland studies by testing the impact of sampling frequency on nutrient load calculations concerning the inflow and the outflow load of the study wetland.

2. Material and methods

2.1. Study site

Our study wetland was excavated in early winter 2010 in an abandoned agricultural field growing meadow vegetation and named the Nummela Gateway Wetland. Old drainage ditches were blocked to ensure water only one inlet route to and one outlet route from the wetland. Water level was set by a bottom dam constructed at the outlet to keep the water level higher compared to nearby lake and to invite wetland vegetation to self-establish. The wetland has an area of 0.5 ha during mean water level counting for circa 0.1% of the 550 ha Kilsoi stream watershed. Water purified by the wetland is discharged to Lake Enäjärvi. The lake watershed area is 34 km^2 and it is located at the headwaters of the River Siuntio which drains to the Baltic Sea. The ecological status of the lake is poor and it suffers from cyanobacterial blooms that restrict recreational use during summer and suffers from anoxia during ice cover season. The wetland was originally constructed to reduce external pollution loads carried by the Stream Kilsoi to the receiving lake as well as to support biodiversity and also to provide an urban park. At the time of presented monitoring forests cover 43%, urban areas 46% with additional urban parks 7%, and agricultural fields 14% of the wetland's catchment area (Fig. 1). The P load from the catchment agricultural land to the wetland has been estimated to be over 10 times higher than P load from the catchment urban area (0.8 vs. 0.07 kg/ha respectively, unpublished data).

2.2. Monitoring of water quality, flow and weather

Monitoring stations were established at the inflow (60.328292926°N, 24.335647020°E) and at the outflow (60.328145576°N, 24.337767514°E) of the Gateway wetland. Distance between the two monitoring stations along the flow path was 250 m during normal flow conditions. Turbidity and dissolved oxygen concentration were measured at 10 min interval with YSI sensors (YSI Inc., Yellow Springs, OH, USA) and nitrate nitrogen (NO_3–N) with Scan sensors (Scan gmbh, Austria). Data from the Scan sensors were calibrated on the basis of manual samples of NO_3–N analysed in laboratory. When turbidity exceeded 400 FTU measuring the NO_3–N was interrupted. The recorded data was transmitted to a data server over a gsm-network and visualized in on-line data service. Single grab samples were taken during different flow and concentration circumstances to gather sensor calibration data. The TP (SFS 3026) and NO_3–N (SFS EN ISO 13395/DA) concentrations from both monitoring sites were analysed according to European or Finnish standard methods in an accredited laboratory.

Flow velocity and water level were measured at the inflow of the wetland with acoustic flow meter (StarFlow, Unidata Pty Ltd., O'Connor, ACT, Australia). At the outflow water level was measured with pressure gauge (STS Sensor Technik Sirnach AG, Sirnach, Austria). Discharge was calculated as a function of flow velocity and cross section area of certain water level. Outflow discharge was calculated on the basis of inflow discharge and the wetland's own catchment size (540/550 ha). The outflow water level was used to set the flow peaks in right place at the outflow hydrograph.

Local weather conditions were recorded with Vaisala WXT weather transmitter at the inflow monitoring station. Rainfall, wind speed and direction, temperature and relative humidity were recorded continuously at 10 min interval.

2.3. Deriving continuous TP data and load calculations

Sensor turbidity was used as a surrogate measure to concentration of total phosphorus (TP). The TP concentrations were calculated based on the sensor-recorded 10 min frequency turbidity data. A linear regression analysis was used to estimate TP (μg/l) from turbidity for data from the years 2013 and 2014. Turbidity and TP (analysed in laboratory; $TP = 1.09Tur + 28.4$, $n = 56$, $R^2 = 0.91$, $n = 29$) were related to calculate TP loads every 10 min by multiplying concentration by discharge Q ($l\,s^{-1}$). Turbidity and TP relationships were noticed to be similar at both measuring points and thus the same equation was used to establish TP values for both the inflow and the outflow of the wetland.

Annual, monthly and daily P and NO_3—N loads were computed as the total sum of 10 min loads (Eq. (1)).

$$L = \sum_{i=0}^{n} QiCi \tag{1}$$

where L is the annual, monthly or daily load, Qi the discharge at time t and Ci the concentration at sampling time t.

2.4. Impact of sampling frequency

To assess the benefit of HFM in evaluating wetland impacts and functioning less than monitored frequency TP and NO_3–N loads were obtained by subsampling TP and NO_3–N concentration/discharge pairs from the collected 10 min interval data. Sampling intervals were set as: daily (365 samples/year), weekly (52 samples/year) and monthly sampling (12 samples/year). Sampling time was decided to be 12:00 a.m. for the daily interval, 12:00 a.m. on Mondays for the weekly sampling, and 12:00 a.m.