Ecological Engineering 103 (2017) 404–414

Contents lists available at ScienceDirect

Ecological Engineering

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

Lessons learned? Effects of nutrient reductions from constructing wetlands in 1996–2006 across Sweden

Berit Arheimer*, B. Charlotta Pers

Swedish Meteorological and Hydrological Institute (SMHI), Folkborgsv 17, 60176 Norrköping, Sweden

ARTICLE INFO

Article history:
Received 30 March 2015
Received in revised form 28 January 2016
Accepted 28 January 2016
Available online 16 February 2016

Keywords:
Nutrient reduction
Measure programmes
Constructed wetlands
Modelling
Large-scale impact

ABSTRACT

Water authorities are currently preparing the second river basin management plans to improve water status in Europe according to the Water Framework Directive (WFD). The on-going efforts of wetland constructions are related to historical efforts in draining land and lakes for agriculture. In Sweden, one of the major problems for surface water is eutrophication caused by diffuse pollution of nitrogen and phosphorus from agriculture. For the whole country, more than 2000 constructed wetlands covering in total 76,000 ha are now suggested to improve the water status. However, this is a small number for the size of the country. This study presents detailed calculations of effects from previous wetland constructions during the years 1996–2006, in which 1574 wetlands (in total 4135 ha) reduced the load to the sea by 0.2% for nitrogen and 0.5% for phosphorus. Even with more optimal allocation, increasing the efficiency, the maximum effect on the total river load would have been small. The simulated efficiency of wetlands varied between catchments in a range of 0.1–340 kg ha^{-1} yr^{-1} for N and 0.01–37 kg ha^{-1} yr^{-1} for P. The variation between wetland efficiency could be explained by large-scale patterns of nutrient concentrations and water discharge or by the specific location of the wetland within a catchment. A sensitivity study showed that each assumption behind the model and the model set-up contributed to uncertainty in the simulation results, but the largest uncertainty refers to the estimation of wetland-catchment area, model parameters and nutrient load. The study involved a lot of data-mining as most wetlands constructed were not accompanied with monitoring programmes, metadata and information on wetland characteristics. It is shown that Sweden still is very far from reconstructing natural conditions, and that more radical measures and combinations of measures are needed to achieve the WFD goals of good water status.

1. Introduction

During the last century, human activities such as agriculture, industry and transportation have increased the mobility of nutrients from land to aquatic ecosystems (e.g. Meybeck, 2002; Vörösmarty et al., 2010; Falkenmark, 2011) and as a consequence eutrophication is a major issue affecting most surface waters (Smith and Schindler, 2009; Grizzetti et al., 2012; Romero et al., 2012). However, during the last decades, measures to reduce riverine nutrients have been implemented across Europe in form of waste-water treatment, better agricultural practices and restricted use of phosphorus (P) products (EEC, 1991a,b). This have resulted in decreased phosphate and/or nitrate concentrations since the mid-1990s in several European rivers such as the Elbe (Lehmann and Rode, 2001), the Seine (Billen et al., 2007), the Rhine (Hartmann et al., 2007), Mediterranean rivers (Ludwig et al., 2009), the Thames (Howden et al., 2010), the Danube (Istvánovics and Honti, 2012), as well as for Swedish rivers (Grimvall et al., 2014).

In spite of the improvements, the current most common pressures to surface waters in EU member states are still diffuse sources and hydromorphological alterations (EEA, 2012), which causes nutrient enrichment and altered habitats (Künitzer, 2013). For nutrient load in rivers, the main sources across Europe are agriculture and point-sources (Donnelly et al., 2013). At present, European water authorities are preparing measure plans to improve the water status, which should be reported by the end of 2015 according to the second cycle of the Water Framework Directive, WFD (EC, 2000). In Sweden, the measure plans are currently available at http://www.vattenmyndigheterna.se for participatory dialogues with stakeholders. Especially the southern districts are very concerned with eutrophication (Vattenmyndigheterna i samverkan, 2014a,b,c) both for inland and coastal waters. Moreover, Sweden has committed to the Helsinki Commission (HELCOM) to implement the Baltic Sea Action Plan (BSAP), which

* Corresponding author. Tel.: +46 733961439.
E-mail address: berit.arheimer@smhi.se (B. Arheimer).

http://dx.doi.org/10.1016/j.ecoleng.2016.01.088

is an ambitious program to restore the Baltic Sea in good ecological status by 2021 (HELCOM, 2007).

Among the measures proposed to fulfil both the WFD and the BSAP, are various wetlands constructed in the landscape. Natural wetlands are known for reducing diffuse nutrient loads (Mitsch et al., 2002; Fisher and Acreman, 2004; Verthoeven et al., 2006; O'Geen et al., 2010) and in Sweden large wetland areas disappeared during the 19th and 20th century to increase agricultural yields. In total about 2500 lakes were shrunk or dried out, and 30,000 soil-drainage projects were performed (SMHI, 1995). At the end of the 19th century some 10,000 ha per year were transformed into arable land and agricultural practices became more efficient. As a consequence the nutrient leaching, load and natural removal processes changed over time (e.g. Hoffman et al., 2000; Andersson and Arheimer, 2003).

The opposite trend to construct wetlands in the landscape started in Sweden during the late 1980s. The reasons were several, including bird watching or hunting, biodiversity, landscape reconstruction and nutrient reduction. To begin with, very high nitrogen (N) reduction rates were proposed, based on empirical data including wetlands for wastewater treatment with high concentrations and regulated flow (e.g. Fleischer and Stibe, 1991). A national research programme on wetlands and lakes as N traps was reported in 1994 (Jansson et al., 1994). From a hydrological point of view, however, critical questions followed whether these results could be realistic for natural conditions (Bergström, 1991). Subsequent modelling efforts showed that natural fluxes and allocation strategies had a significant impact on the wetland efficiency on river load (Arheimer and Wittgren, 1994, 2002).

Hence, some guide-lines were proposed for wetland constructions to reduce the load on Swedish inland waters and coastal zones efficiently; the wetlands should be allocated in coastal agricultural areas, downstream from lakes and where summer load is a large part of the annual load (Arheimer and Wittgren, 1994). Moreover, >1% of the catchment area should be converted into wetlands to receive >10% N reduction. This latter statement was found unrealistic in practice and empirical field studies suggested 0.4% of the arable land to be converted in southern Sweden (Holmström, 2003). The importance of wetland design for efficient nutrient reduction in Nordic climates has also been high-lighted repeatedly, e.g. impact of water residence time (Koskiaho et al., 2003), flow uniformity and effective volume (Persson et al., 1999) and plant species (Kallner Bastviken et al., 2005).

In Sweden the government has, among other measures, allocated more than 1300 million SEK (approximately 130 million Euros) for wetland constructions in the landscape during the period 1996–2011 (Table 1). When subsidies were given by the Swedish government for wetland constructions, however, no clear guidelines for allocation strategies or design were given, nor requests of control programs or monitoring of effects. Subsidies were mainly given within a rural development program (RUP: 1996–2006), and a local investment program (LIP: 1998–2002). In total, more than 5000 ha of wetlands were constructed for different purposes, and about half of them were dedicated primarily to nutrient reduction.

Table 1
Planned and constructed wetlands across Sweden from 1996 and onwards.

	No.	Area (ha)	Cost (Euro)
Planned: WFD 2nd programme of measures (2015–)	2184	76,080	3650 million
Constructed in 2009–2011	564	1468	70 million
Constructed in 1996–2006	1574	4135	60–100 million

For the wetlands constructed 1996–2006 with a total connected area of 2952 km^2, the cost was on average €51,000 per wetland when calculated for a total cost of €80 million. The cost was €271 per ha of connected catchment area and €19,000 per ha of wetland area.

In this study, we explore the total effects of wetlands constructed between 1996 and 2006 for reducing nutrient pressure on inland and coastal zones in Sweden. We assume that nutrient load reduction by wetland constructions and variability in efficiency can be estimated by using a dynamic and integrated catchment model with spatial distribution. Similar landscape analysis have been performed for single catchments using various model concepts (e.g. Tonderski et al., 2005; Hattermann et al., 2008; Hansen et al., 2009; Passy et al., 2012; Pärn et al., 2012). However, no study of our knowledge has yet encompassed the national scale using a multi-basin approach for thousands of wetlands as in this paper. Three questions are addressed in the study:

(1) How effective in reducing nutrient load are the wetlands that were constructed at a large-scale across Sweden in 1996–2006?
(2) How robust are the results and conclusions from this modelling study?
(3) What lessons did we learn for the future?

2. Material and methods

The wetlands are all constructed in southern Sweden (Fig. 1) and the study is limited to an area of 164,000 km^2, of which about 17% is agricultural land and 11% surface water (i.e. lakes). Less than 2% of this area is connected to the wetlands constructed. The constructed wetlands show higher density in southernmost part and south of Lake Vänern. In these areas agriculture is dominating and the nutrient leakage to surface water is high. Detailed information

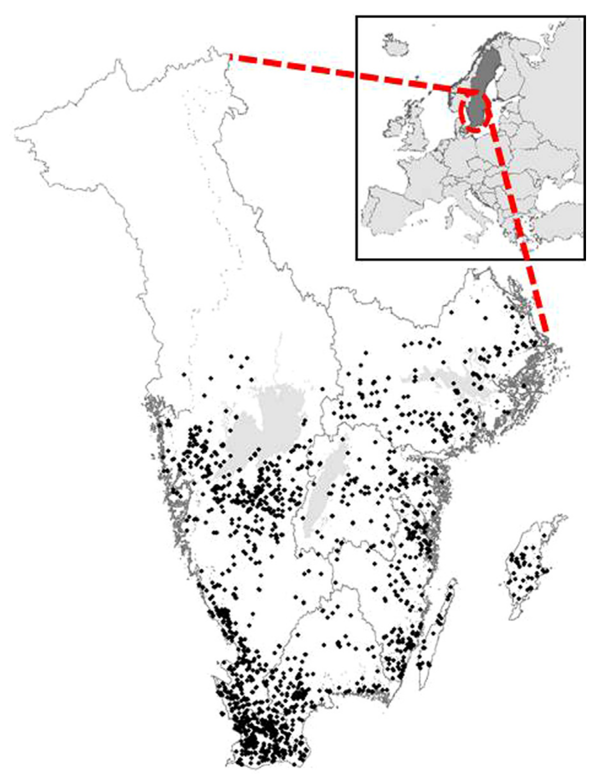

Fig. 1. Location of wetlands constructed in Sweden during the years 1996–2006.