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Implementing surface flow constructed wetlands in Denmark using a new layout design

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INTRODUCTION

Nutrient enrichment can have detrimental effects on aquatic ecosystems, as excess nitrogen (N) and phosphorus (P) concentrations can lead to eutrophication, biodiversity loss, hypoxia, and loss of ecosystem services (Smith et al., 1999). Agriculture is one of the major sources of N and P to aquatic ecosystems worldwide as well as within the European Union. To mitigate these detrimental effects the Water Framework Directive 2000/60/EC by the European Union has implemented several environmental policies to protect freshwater resources (European Commission, 2000).

Denmark is an intensely cultivated country with approximately 62% of the land area being agricultural land (Danmarks Statistik, 2017). Furthermore, more than 50% of the agricultural land in Denmark is drained (Møller et al., 2018). Nitrogen passing through the subsurface drains is prevented from undergoing the natural N removal mechanism in soils (Blicher-Mathiesen et al., 2019), which underlines the need for implementation of mitigation measures targeting agricultural drainage water.

In 2015 the Agreement on the Food and Agriculture Package was implemented to allow Danish farmers to fertilize to economic optimum, breaking with nearly two decades of sub-optimal fertilization. To comply with the EU directives while maintaining a high agricultural production a new nutrient management plan was implemented. This initiated a new era of management of agricultural nutrient losses in Denmark with emphasis on local environmental needs and mitigation measures. Several nutrient transport mitigations measures have currently been implemented or are undergoing development (Hoffmann et al., 2020). Surface flow constructed wetlands (CWs) are a popular best management practice when treating agricultural drainage water (Tanner et al., 2005). In 2010 the first two CWs were constructed in Denmark to investigate performance under Danish conditions using a new layout design. Experienced gained from these have been used to implement CWs in Denmark on a broad scale.

This study presents the design and implementation of CWs in Denmark and discusses their performances in general while using data from two CWs to illustrate performance over time.

METHODS

The CWs in Denmark follow the same design consisting of two components: (1) a

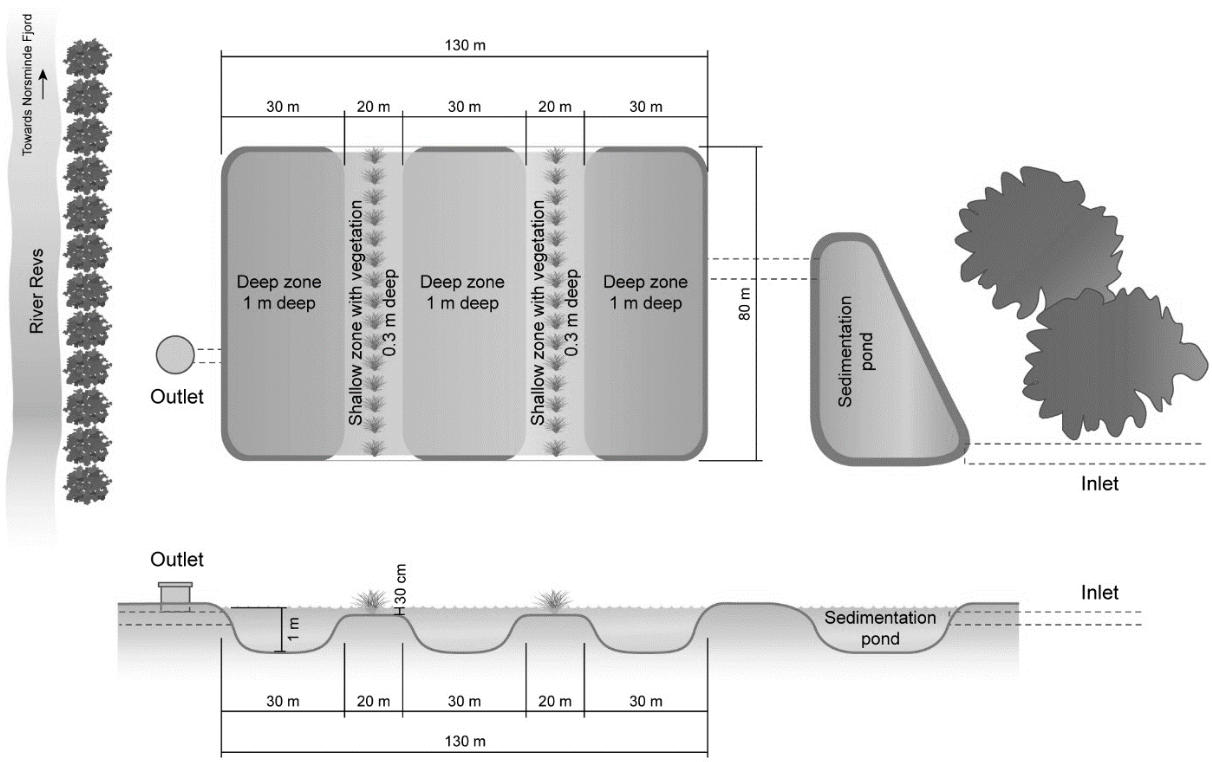

Fig. 1. Principle sketch of a surface flow constructed wetland consisting of a sedimentation basin and a wetland with a sequence of deep (~1m) and shallow (~0.3 m) zones.

sedimentation pond with a depth of 1 m and (2) the CW which consist of three deep open surface basins separated by two shallow zones with vegetation (Fig.1.). The sedimentation pond receives drainage water directly from agricultural fields. The deep basins of the CWs are 1 m deep to optimize the hydraulic retention time, while shallow zones of 0.3 m are designed to sustain vegetation and a continuous input of carbon.

The CWs at Fillerup and Fensholt are both constructed near Odder, Denmark. Fillerup was constructed in 2010 with a catchment area of 38 ha agricultural field. The CW is 0.298 ha in size and constitutes 0.78% of the drained area. The CW at Fensholt was constructed in 2015 and receives drainage water from 33 ha. It constitutes 0.74% of the drained area with a size of 0.245 ha.

Water samples were collected using ISCO samplers and all analyses comply with European standards. The N removal and P retention is evaluated using a mass balance approach.

RESULTS and DISCUSSION

In general, CWs in Denmark have shown to be effective for both N removal and P retention with mean removal rates of 472 and 31 kg ha^{-1} y^{-1} and mean removal efficiencies of 23 and 45%, respectively (Table 1). Nitrogen removal in CWs occurs through denitrification, while the P retention occurs mainly due to sedimentation of particulate P (Mendes et al., 2018). The efficiency of nitrogen removal shows strong seasonal variation, due to variations in hydraulic retention time (HRT) and temperature.

Table 1. Overview of absolute and relative nutrient removal efficiency (mean ± sd) of Danish surface flow constructed wetlands.

Sites (n)	Years	Removal rate ($kg\ ha^{-1}\ y^{-1}$)		Removal efficiency (%)	
		TN	TP	TN	TP
13	44	472 ± 372	31 ± 26	23 ± 10	45 ± 20

Years: number of years monitored. After Hoffmann et al., 2020.

For the half year periods of July 2017 to June 2020 at Fillerup, the total nitrogen (TN) inlet varied between 206 and 642 kg, while the outlet varied between 193 and 631 kg. Resulting in a TN removal of 13-167 kg, or 44-560 kg/ha, and a removal efficiency of 6.3-26 % (Table 2). The total phosphorus (TP) inlet varied between 1.67-11.3 kg, while the outlet was 0.670-5.98 kg and had a removal efficiency between -1.6 and 60%. The CW at Fensholt received 347-615 kg of TN and 5.0-29.8 kg of TP, while 52-107 kg TN and 2.0-7.8 kg TP were measured at the outlet. Resulting in efficiencies of 13-19% and 36-62% for TN and TP, respectively.

A review by Carstensen et al. 2020 found that CWs treating agricultural drainage water had TN removal means of 41% within a range of -8 to 63% (Carstensen et al., 2020), which is a higher removal mean than for the two CWs of this study. However, studies of Swedish CWs under similar climatic conditions have found removal efficiencies of 3-15 % (Bastviken et al., 2009; Strand & Weisner, 2013). The CWs at Fensholt and Fillerup were both constructed as full-scale testing facilities and knowledge gained have been used to determine the standard for CWs in Denmark. Today CWs must be 1-1.5% of the drained catchment to ensure a minimum HRT of 24 hours in winter, where the largest drainage discharges occur. Fillerup and Fensholt are 0.78 and 0.74% of their catchment areas, respectively, and a larger CW area would improve the efficiencies.

Table 2. Total nitrogen (TN) removal and total phosphorus (TP) retention at the surface flow constructed wetlands of Fillerup and Fensholt, Jutland, Denmark.

Study site	Period	TN removal (kg/ha)	TN-removal (%)	TP retention (kg/ha)	TP retention (%)
Fillerup	07/17-12/17	560	26	17.8	47
	02/19-06/19	44	6.3	3.36	60
	07/19-12/19	289	12	14.8	55
	01/20-06/20	235	16	-1.0	-3.6
Fensholt	07/17-12/17	437	19	31.8	36
	02/19-06/19	212	15	8.16	40
	07/19-12/19	327	13	24.9	43
	01/20-06/20	314	19	53.1	62

The average TP retention efficiencies of Fillerup and Fensholt (Table 2) are higher than the general average for CWs of 33%, ranging from -103 to 68% (Carstensen et al., 2020). The danish CWs generally show high TP retentions with an average efficiency of 45% (Table 1) (Hoffmann et al., 2020). It is noteworthy that soluble reactive phosphorus had a net retention of 67 and 54% for the whole period, while particulate P had a net loss of -66 and -97% for Fillerup and Fensholt, respectively. This contradicts the findings of Mendes et al. (2018). Further investigations are needed to evaluate the processes controlling P dynamics in the CWs.

CONCLUSIONS

Surface flow constructed wetlands treating agricultural drainage waters has been successfully implemented in Denmark. Knowledge gained at the first CWs have been used to optimize the design and implement CWs as the first Danish mitigation measure targeting local environmental needs.

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STØTTET AF

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